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Rates of regeneration establishment on stands harvested from 1980-1982 on the Missoula Ranger District, Lolo National Forest

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Rates of Regeneration Establishment

on Stands Harvested from 1980-1982 on the

Missoula Ranger District, Lolo National Forest

By

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Abstract

One of the most critical issues in second-growth timber management is how long it takes for regeneration to become established on different types of harvested sites. To examine this question, four models were developed from the results of regeneration surveys taken on 54 stands harvested from 1980 through 1982 on the Missoula Ranger District in western Montana. The data were analyzed using linear regression and logistic probability techniques in a modified case study approach.

There was a considerable amount of unexplained variation in each of the models; this is not surprising given the many influences on tree regeneration which were not measured in this retrospective study. Variables were included in the models on the basis of the statistical significance of their coefficients and their overall contribution to model significance.

Weather conditions and cone crop intensities during the study period were examined and discussed, but were not incorporated into the models. Analyses of weather and cone crops indicated that during the period of 1978 to 1988, the cycles of these two major sources of variation were not unusual in comparison to those of preceeding years.

It was evident from the survey data and models described in this study that only under optimum site and managerial conditions can harvested stands in this area be expected to regenerate to certifiable levels within five years after disturbance. This finding has important implications in terms of management and planning on forested lands administered by the United States Forest Service.

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Dedication

To the loggers, treeplanters, and stand examiners who have touched the forests and clearcuts with their bodies and spirits:

Naturam expellas furca, tamen usque recurret

"You may drive Nature out with a pitchfork,
but she will keep coming back"

Table of Contents

List of Tables

List of Figures

CHAPTER 1

Introduction

Second-growth forest management relies on silvicultural treatments to establish and maintain productive timber stands. A major objective of timber stand establishment is to reach desired levels of seedling stocking as soon as possible after a harvest. Estimates of the rates of regeneration establishment on different types of sites are useful for developing silvicultural prescriptions and for monitoring treatment results on individual stands; on a larger scale, these estimates also have implications in forest management and planning.

Economic analyses of timber management efficiency are based on the net present value of timber harvests, i.e., the costs associated with stand management during a rotation are subtracted from the value of the timber harvested at the end of the rotation.[1] Delays in stand regeneration cause reductions in the net present value of a future harvest in two ways: first, the value of the timber is discounted over a longer period of time; secondly, if remedial treatments (such as replanting or additional site preparation) are needed, their costs must be subtracted from the discounted value of the next harvest.

Differences in site productivity add to the complexity of second-growth timber management. On productive sites, the value of timber

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[1] A timber rotation is "the planned number of years between the formation or regeneration of trees and their harvest at a specified stage of maturity" (Lolo National Forest Plan, 1986, VII-34), and is generally based on the culmination of mean annual increment (Ibid, Appendix B-72). The average rotation age for regenerated stands on the Lolo National Forest is 85 years (Ibid, Appendix C-5).

harvested at the end of a rotation usually exceeds the costs associated with management (including harvesting) because net volume growth more than compensates for the discounting of timber values over time. The costs of treatments which promote regeneration establishment and growth on these sites are generally considered rational investments.

On harsher, less productive sites, projected timber values may be exceeded by management costs, especially in areas where difficult access adds to treatment expense. In those cases, the risk of incurring negative net present values limits the range of economically justifiable treatment prescriptions.

In the mountains surrounding Missoula, Montana, several factors combine to create harsher and more irregular site conditions than those found in more productive timber-growing regions: a short growing season, shallow and infertile soils, steep slopes, cold winters, moderate precipitation, periodic droughts, and occasional extreme or unseasonable temperatures. Analysis of data from regenerated sites in this area allows managers to adjust natural stand yield tables and to calibrate stand projection models which have been developed in other regions.

Beyond their importance in stand management, realistic estimates of regeneration rates are essential in determining harvest levels on public forest lands. Harvest levels (also called allowable sale quantities or allowable cuts) are specified in the forest planning process according to the sustained yield.[2] Timber yields are considered

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[2] U.S. Congress (1974), Section 13(a) of the Forest and Rangeland Renewable Resources Planning Act.

sustainable if the amount of timber to be harvested within a particular time period does not exceed the average rate of net volume growth.

Increases in harvest levels on National Forest lands are permitted when planting and thinning are expected to improve volume growth. However, any increases in harvest levels based on intensive management practices must be decreased by the end of each ten-year planning period if "such practices cannot be successfully implemented or funds are not received to permit such practices to continue substantially as planned."[3]

In the 1970's, Congress enacted legislation related to forest planning and management on federal lands in order to address many concerns about forest resource use in the United States. The National Forest Management Act of 1976 (NFMA),[4] includes several references to reforestation on National Forest System lands. The following two are the most relevant to this study:

> 1. (Forest Service) "regulations shall include... guidelines for land management plans which... insure that timber will be harvested from National Forest System lands only where... there is assurance that such lands can be adequately restocked within five years after harvest" (Sec.6(g)(3)(E)(ii));
>
> 2. "All national forest lands treated from year to year shall be examined after the first and third growing seasons ... as to stocking rate, growth rate in relation to potential and other pertinent measures. Any lands not certified as satisfactory shall be returned to the backlog and scheduled for prompt treatment" (Sec.3(d)(1)).

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[3]U.S.Congress, The Forest and Rangeland Renewable Resources Planning Act of 1974 (88 Stat. 476, as amended by the 1976 National Forest Management Act); Section 6(g)(3)(D)).

[4]The National Forest Management Act of 1976 (U.S. Congress, 1976, 90 Stat. 2949); the NFMA includes twelve sections which amend the Forest and Rangeland Renewable Resources Planning Act of 1974.

In 1979, Forest Service regulations were promulgated to carry out the provisions of the NFMA by establishing standards and guidelines to be used in the forest planning process; the regulations were revised in 1982 after a review by the Presidential Task Force on Regulatory Relief.[5] The regulations specify several criteria for identifying lands which are not suitable for timber production, one of which[6] is whether or not there is reasonable assurance that such lands can be adequately restocked as provided in the following paragraph:

> When trees are cut to achieve timber production objectives, the cuttings shall be made in such a way as to assure that the technology and knowledge exist to adequately restock the lands within 5 years after final harvest. Research and experience shall be the basis for determining whether the harvest and regeneration practices planned can be expected to result in adequate restocking. Adequate restocking means that the cut area will contain the minimum number, size, distribution, and species composition of regeneration as specified in regional silvicultural guides for each forest type. Five years after final harvest means 5 years after clearcutting, 5 years after final overstory removal in shelterwood cutting, 5 years after the seed tree removal cut in seed tree cutting, or 5 years after selection cutting (36 CFR 219.27(c)(3)).[7]

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[5] U.S.D.A. For.Serv. (1982) 36 CFR Part 219.

[6] U.S.D.A. For.Serv. (1982) 36 CFR 219.14(a)(3).

[7] Although the five-year limit for restocking specified in this regulation does not technically begin until after the final removal of any remaining overstory, the importance of obtaining adequate stocking within or soon after five years of any type of regeneration harvest is recognized by and reflected in U.S. Forest Service Region 1 policy: for stands harvested using the shelterwood or seed tree systems, the expected number of years to certification for natural regeneration is defined as 5 to 7 years after a cycle that includes site preparation, a fall seed crop and a growing season; for plantations, the expected time for certification is 3 to 5 years after the first growing season following planting (Sec. 234, Reforestation Handbook, R-1 FSH 12/88 Amend 36).

The above paragraph is one of the many "minimum specific management requirements" set forth in the regulations to guide all phases of the forest planning process.[8] Included with the minimum specific requirements for even-aged management is a definition of "openings:" "... As a minimum, openings in forest stands are no longer considered openings once a new forest is established."[9]

In conjunction with limitations on the size of harvests set forth in the regulations,[10] the definition of "openings" has an important implication for harvest scheduling; i.e., the units within a cut block must be certified as stocked before harvests on adjacent blocks can commence.[11] A feedback loop therefore exists which depends on exchanges of information about the results of regeneration treatments and the scheduling of future harvests.

Subsequent to the NFMA and its ensuing regulations, each Forest Service Region and Forest developed stocking guidelines for regeneration harvests according to productivity class.[12] The guidelines recommend

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[8] U.S.D.A. For. Serv. (1982) 36 CFR 219.27.

[9] U.S.D.A. For. Serv. (1982) 36 CFR Part 219.27(d)(1).

[10] In Montana, generally 40 acres (U.S.D.A. For. Serv. (1982), CFR 219.27(d)(2)).

[11] Additional requirements are specified in the Regional Guide for meeting wildlife habitat and visual quality objectives. A 1973 Region 1 policy statement on clearcutting (which has since been deleted from the Forest Service Manual) states: "With a few exceptions, about 15 years are required in the Northern Region for a clearcut unit to recover sufficiently to consider similar treatments in immediately adjacent units" (Forest Service Manual 2403.2--2, 8/73 R-1 Supp.153).

[12] See Appendix B for Region 1 and Lolo National Forest stocking guidelines.

minimum stocking levels for certifying a stand as established, but are not intended to be applied to specific sites.[13] The quantity and type of regeneration required to certify a regeneration harvest on National Forest lands are ultimately determined by the silviculturist who writes the stand prescription, based on prior experience and research applicable for that type of site.

To assist the silviculturist, each harvested stand is surveyed periodically to provide data for analyzing the effectiveness of its prescription.[14] Results of regeneration surveys are also used in monitoring and evaluating the Forest Plan.[15]

In what ways can the survey results be analyzed to provide useful information for timber managers? Is there any indication from survey data that specific types of sites cannot meet minimum regeneration standards as defined in the NFMA and the Forest Service Regulations?

The Problem

For the reasons discussed in the preceeding pages, silviculturists and forest planners need estimates of regeneration establishment rates which are: (a) quantitative, (b) locally appropriate, and (c) indicative

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[13]U.S.D.A. Forest Service, Reforestation Handbook, Section 211, (FSH) 2409.26b, April 1985, Amend 27; and Lolo National Forest Regeneration Risk Assessment and Stocking Level Guides, May 1987, p. 22.

[14]U.S.D.A. For.Serv. Handbook, 1985, FSH 2409.17-8.2e 7/85 R-1 Supp.1.

[15]The Lolo National Forest Plan, Feb. 1986, pp. V-3 and V-9; Regeneration Status Reports and Indices which summarize records from the Timber Stand Management Record System are used for monitoring regeneration treatments at the District, Forest and Regional levels.

of treatment results on specific types of sites. There is a wealth of information from experimental studies identifying and quantifying the factors influencing forest regeneration in the vicinity of Missoula, Montana (see Bibliography). However, there are no published studies which have documented and analyzed the results of recent silvicultural practices on Forest Service lands in this particular area for the purpose of estimating the rates of establishment of natural and planted regeneration over time on different types of sites.

Study Objectives

The overall objective of this study was to provide a data record and analysis of available stocking survey results for areas on the Missoula Ranger District of the Lolo National Forest which had regeneration harvests from 1980 through 1982. The main questions of interest in this study were:

1. Given certain site conditions and treatments, how much time did it take for the study stands to meet the regeneration goals defined in their prescriptions?
2. What conclusions may be reached about the applicability of this data to predicting stocking over time?
3. What recommendations for management and future research can be made?

Study Analyses

Using data from available surveys of all stands with regeneration harvests from 1980-1982 on the Missoula District, I conducted the following analyses (see Appendix D and Chapter Five for data summaries, and Chapter Four for a more detailed description of the variables and methods used):

1. Using ordinary least squares multivariate regression, models of the rate of establishment were developed for:

a. natural regeneration, and

b. combined natural and planted regeneration.

The dependent variable in these two analyses was "effective stocking" (this measure is explained in Chapter Three), and the independent variables reflected site characteristics and time since disturbance. The models are discussed in Chapters 7 and 8.

2. Using LOGIT, a program for estimating the outcome of a two-way decision using the cumulative probability function, two non-linear models of the probability of regeneration establishment were developed; the dichotomous dependent variable in both models was whether or not a stand was certifiable as stocked within one of two time frames. The models are discussed in Chapter 9.

3. Weather conditions and cone crop intensities on the Missoula Ranger District during the period of 1978 through 1988 were summarized and compared with previous periods in order to examine the applicability of the models to harvests completed in years other than 1980 to 1982. The weather and cone crop analyses are presented in Chapter 6.

CHAPTER 2

Literature Review

Timber stand regeneration in western Montana has been examined in many site-oriented studies. This review is limited to five recent studies in the Northern Rocky Mountains, four of which used a modified retrospective case study approach to develop models for predicting probabilities associated with the regeneration of harvested sites. The fifth study combined silvicultural insight and experience, along with timber volume growth and economic models, to develop probabilities and associated costs of establishing natural and planted regeneration.

The Regeneration Establishment Model, described in Ferguson and Crookston (1984), and in more detail in Ferguson, Stage and Boyd (1986), is a predictive model applicable to the grand fir-cedar-hemlock ecosystem of the Northern Rocky Mountains. Developed as an extension of the Prognosis model for stand development (Stage, 1973), this model predicts an expected inventory of regeneration by linking logistic and linear regression equations which characterize the probability of natural regeneration, allowing for adjustments from user-input values for expected survival rates of plantations, and the type and timing of site preparation.

The study involved a retrospective approach resembling the case history method except for the rigorous sampling process and large sample size. The model equations were derived from analyses of 4964 1/300 acre plots taken in 1975 and 1976 on 190 stands harvested from 1959 to 1972 on National Forest, state, and private timberlands in Idaho, northeast Washington and northwest Montana. The 190 stands were randomly selected from 4,107 stands which had been stratified by four regeneration harvest methods, three site preparation methods, and three major habitat types.

Both planted and naturally regenerated stands were included in the analyses since the exclusion of plantations might have biased the sample toward stands which regenerated well (plantations often turn out to have more than adequate natural stocking, but the initial decision to plant is usually made when a delay in natural regeneration of desirable species is expected). All established seedlings were recorded on each plot; trees were considered established if they were at least 1 foot tall for shade-intolerant species, and 6 inches tall for shade-tolerant species.

The authors developed logistic regression equations for estimating three dependent variables: probability of stocking, distribution of the number of trees per plot, and probability of occurrence on a plot for ten different species. Probability of stocking was analyzed separately for different site preparation methods, and probability of species occurrence was analyzed separately for advance, subsequent and excess regeneration. Log-linear regression equations were used for predicting tree heights by species.

Independent variables used in the equations included slope, aspect, elevation, time since disturbance, residual overstory basal area, and class variables for habitat type, geographic location, site preparation method, and plantation effects. The variables were selected using a stepwise-screening algorithm,[16] and regression coeficients were estimated using a non-linear logistic program called RISK (Hamilton 1974). The equations were tested for goodness of fit at the .05 significance level, and were also evaluated as to whether they reflected known biological relationships; the overall model was examined to see if predicted outcomes were reasonable.

In the logistic model for probability of stocking, the dependent variable had a value of 1 if a plot was stocked with at least one tree, and a value of 0 if not stocked (2968 of the 4964 plots were stocked). *Ceteris paribus*, i.e., keeping the other variables constant, the lowest probabilties of stocking occurred on the relatively warm and dry habitat type of Abies grandis/ Pachystima myrsinites. North-facing aspects regenerated sooner than south-facing slopes, but over time, the rate of increase in stocking was higher on south than on north aspects. The effect of aspect on east and west facing slopes was approximately equal, and was intermediate between that of the north and south aspects. The positive and negative effects of aspect were accentuated by slope steepness.

Stocking probabilities were initially higher for plots without site preparation (this was attributed to less disturbance of advance regeneration), but the rate of increase in stocking over time was higher on plots which had some type of site preparation (aspect influenced the increment in stocking over time more than site preparation type). The

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[16]SCREEN, described in Hamilton and Wendt (1975), was designed to analyze dichotomous dependent variables by classifying the variation in any one independent variable into discrete levels so that each plot falls into one class for each independent variable.

response curve for elevation was quadratic, i.e., probabilities of stocking were highest at middle elevations (3500 to 4000 feet) and lowest at the high and low extremes of the sample.

Equations for the other dependent variables (number of trees per plot, species occurrence and tree heights) were developed from the stocked plot data, and exhibited similar effects due to slope, aspect, habitat type and elevation, depending on the regeneration species. The class variable of PLANT, which had a value of 1 if a stand had been planted and 0 if not, had a negative effect on the probability of stocking when a plot had no site preparation, and a positve effect with site preparation. Planted stands had fewer trees per stocked plot, but the PLANT variable had a positive effect on species occurrence, with shade-intolerant species showing the most benefit from planting.

Several assumptions were made in the study design and equation-fitting phases: first, the effects of seed crops and weather were averaged out by sampling from sites harvested over a period of fourteen years. Secondly, the influences of soils, diseases and insects were assumed to be represented in an unbiased way through the random selection of sample stands.

A third assumption was that the effects of competition from shrubs, forbs and grasses were represented by other independent variables; for example, variations due to time since disturbance, site preparation method, habitat type, aspect, slope, and elevation likely incorporate some of the effects of vegetative competition on stocking. Since vegetation coverage was not measured at the time of seedling germination, it was not included as a variable in the modelling process.

The authors pointed out that although the retrospective nature of the study design may have precluded measurement of important variables, the data reflected operational harvest and regeneration methods, and thus the Regeneration Establishment Model is useful for predicting what could be expected from silvicultural treatments. Noting that certain species, such as ponderosa pine, western larch, and Engelmann spruce, are often difficult to regenerate naturally, they recommended leaving suitable seed sources and timing site preparation with good seed crops to enhance regeneration of those species. They also emphasized the need for silviculturists to maintain accurate historical records of the effects of treatments, especially if the results of planting are to be modelled (Ferguson et al., 1986).

In a study using similar sampling and modelling procedures, Dolezal (1982) developed natural regeneration establishment models for shelterwood and seed tree harvests on Douglas-fir and grand fir habitat types in northeastern Oregon and central Washington. The population of unplanted stands with harvests from 1967 through 1979 on Boise Cascade lands was stratified by the two habitat type series and three site preparation types (none, mechanical, and pile and burn). Two or more stands were randomly selected from each cell, resulting in 37 sample stands from which 797 plots were taken in 1981.

The resulting models generally reflected expected relationships between independent variables and predicted stocking levels. Some of the results of Dolezal's study are presented in the following paragraphs.

Of the three measures of overstory density examined, trees-per-acre was a better predictor variable for probability of stocking than either basal area or crown competition factor. That relationship was partially explained by differences in shade tolerance by species (e.g., shade-intolerant species occurred most frequently on plots with low overstory densities). In the northeastern Oregon model, the natural logarithm of overstory trees per acre improved the R-squared.

The effects of habitat type and site preparation were examined on both a plot and stand basis; for each of those site variables, using the values obtained on each plot (vs. the stand value attributed to all of the plots located within the stand) provided a better model fit. As with the models described in Ferguson et al. (1986), probability of stocking on the central Washington plots was higher on cooler, moister habitat types and, over time, on scarified sites.

One unexpected outcome was that the probability of stocking decreased over time in the northeastern Oregon models; one would expect stocking to increase over time from additional seeding-in, with minor fluctuations due to seedling mortality. Dolezal suggested that this unusual result may have been due to a single flush of lodgepole pine regeneration from serotinous cones immediately after harvest, followed by mortality with no additional seeding (lodgepole pine was more prevalent on the northeastern Oregon plots, and several of those stands were infested by a gall rust which may have girdled seedlings).

Several variables which were not significant at the .05 level were included in the northeastern Oregon models either because of the importance of the variable in making management decisions (e.g., site preparation) or because they improved the fit of the model (e.g., slope and aspect interactions). Low significance of the site preparation variable was attributed to the variability resulting from different intensities of site preparation, and the timing of site preparation with respect to seed production.

In Dolezal's study, models for northeastern Oregon which included slope and slope-aspect interaction variables had higher R-squared values, but those variables were not significant at the .05 level;[17] their coefficients indicated that optimum stocking occurred on northeast aspects and decreased with increasing slope. Slope was a significant variable in the central Washington models, and had a positive coefficient, indicating that as slope increased, so did the probability of stocking (most of the plots had slopes between 10 and 40%).

Dolezal concluded that more intensive sampling was needed to clarify many of the relationships examined in her study. Because only stocked plots were used in building the models for predicting the probability of species occurrence, number of trees per plot, and tree heights, more plots would be required than initially apparent (in her study, 405 of the 797 plots analyzed were stocked). The limited number of plots representing various site preparation methods precluded a comparison of their effects by habitat type. Gaps which occurred in

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[17]The use of interaction variables to represent the combined effects of slope and aspect is recommended for several reasons. For example, as slope percent increases, the negative effects of a southern aspect are accentuated due to increased radiation up to the angle of slope that is perpendicular to the sun's rays. On steeper slopes, the advantage of a decrease in radiation on any aspect is likely offset by decreasing soil depth (Stage, 1976).

measurements of time since disturbance, elevation, and topographic position could be narrowed by sampling more plots (Dolezal, 1982).

Fiedler (1981 and 1982) examined the probability of stocking after clearcut harvests on several habitat types within the spruce-fir zone in western Montana. In the first study (Fiedler, 1981), a sample was randomly chosen from stands with clearcut harvests from 1963 to 1973 on 21 of the 22 ranger districts on the Bitterroot, Lolo, Flathead and Kootenai National Forests, and on Confederated Kootenai-Salish tribal lands. Stands were rejected for sampling if they had been planted or were not of the subalpine fir (ABLA) series as defined by Pfister, et al. (1977). In 1977 and 1978, 77 stands were surveyed, using 1/300 acre plots located at equal intervals along transects positioned so that elevational and physiographic variation could be sampled, resulting in a total of 1377 plots.

Estimating stocking probability using a dichotomous dependent variable of whether a plot was stocked with one tree or not, Fiedler found significant effects due to habitat type, site preparation method, and time since disturbance. One interesting result was that stocking probabilities on scarified sites were higher than on sites which had been broadcast burned, but only until the ninth to twelfth year after disturbance, depending on the habitat type. He suggested that the negative effects of burning on natural regeneration were ameliorated over time,[18] and cited three studies which reported improvements in the physical and biological characteristics of burned sites over time (Fiedler, 1981).

In a similar study in western Montana, described in Fiedler (1982), both plantations and naturally regenerated harvest units were surveyed. The effect of planting on probability of stocking could not be quantified since almost half of the planting attempts failed while the successful plantations were unnecessary due to adequate natural regeneration. His study suggested that further research consider the effects of planting stock condition, planting crew and method, and planted seedling survival rates.

A different type of study from the above arrived at probabilities of natural and planted regeneration success after round-table discussions between silviculturists on the Lolo National Forest (Christopherson and Applegate, 1987). The study was intended to provide managers with a method for evaluating the economic risk associated with many different types of regeneration treatment scenarios.

Combining their past experience with consideration of local regeneration studies, the silviculturists created scenarios of the results of several regeneration treatments for Lolo National Forest habitat type groups 2 though 5 (these habitat type groups are described

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[18] Post-burn conditions include increased temperatures on blackened surfaces which can cause seedling injury and mortality, and thick ash layers which can prevent seedling establishment. These conditions would change over time due to weathering and revegetation.

in Appendix A). The Timber Economic Analysis System (TEAS) was used to calculate net present values.[19]

For each combination of treatments (e.g., Clearcut-Burn-Plant and Shelterwood-Dozer-Natural), the group estimated the probability of occurence for three "Management Zones" (MZ). The MZ's were defined on the basis of whether corrective actions would be required: "MZ +" indicated the stocking level which would require a future precommercial thinning, "MZ 0" indicated the stocking level which would not require future treatients, and "MZ -" indicated the stocking level requiring planting to meet target stand objectives.

The probabilities associated with the MZ's were based on the silviculturists' estimates of probable regeneration success given cone crop periodicity, habitat type, residual and/or planted species, and site characteristics (slope, aspect, elevations, and soils). Each treatment scenario within each habitat type group was evaluated for the regenerated stand species compositions that were likely to develop as a result of the treatment.

The time frame used in the base study assumed that regeneration (natural or planted) in each MZ occured within two years of site preparation and that all regenerated stands were harvested after 100 years, the average rotation length on the Lolo National Forest. An additional six treatment scenarios for natural regeneration in the Douglas-fir habitat type group were selected to compare present net

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[19]The Timber Economic Analysis System (TEAS) used a discount rate of 4% in determining net present values. The source for projected stumpage price increases is a model developed by Haynes and Adams (1980), which was also used in the Lolo Forest Plan.

values (PNV) resulting from 10, 20 or 30 year delays in regeneration establishment with PNV from the base study.

In this comparison, variables such as species composition and site preparation costs were held constant so that differences between the no-delay scenario and the delay scenarios reflected only the added time before benefits and costs of the next harvest were incurred.[20] The results of the comparison indicated that the present net value decreased by about 3% for 10-year delays, 5% for 20-year delays, and 6% for 30-year delays.

As the authors observed, a large amount of regeneration survey data has been collected on the Districts which requires manual processing for analysis. They outlined several data needs, one of which was to have the results of all stocking surveys entered into the Timber Stand Management Record System (TSMRS).[21] They also emphasized the importance of resurveying all stands after they have been certified in order to quantify the amount of additional ingrowth and to determine whether planted stands would have adequately restocked without planting.

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[20]The authors noted that site-specific adjustments would be required to adequately evaluate the full consequences of regeneration time delay. A delay in regeneration could favor establishment of less desirable species, and the costs of additional treatments, such as scarification and fill-in planting, would decrease present net values even further.

[21]It is now a Regional requirement to report trees-per-acre and stocking percent on the TSMRS for all regeneration exams; TSMRS forms have been revised so that results from previous exams are not replaced with new data.

Discussion of Predictive Models

Predictive models are useful tools for management purposes as long as their underlying assumptions are understood. It is important that statistical models are not applied to situations which are beyond the range of the environmental and management-related data used to create them; for example, stands with steeper slopes or lower elevations than those represented by the data could have appreciably different stocking probabilities from extrapolated predictions. An observation made by Pielou (1983) sums up these limitations: "statistical models reveal possibilities, but not impossibilities."

Studies which combine silvicultural experience and insight with data analysis (such as Christopherson and Applegate, 1987) are likely more useful to managers than statistical analyses alone; however, such studies are influenced by unmeasurable biases. The applicability of this approach depends on continuity and training of personnel, as well as consistency in data collection and recording.

A major consideration in regeneration establishment modelling is that it is very difficult to account for variations due to external factors such as weather conditions, cone crop intensities, and cattle, wildlife, insects and disease. The assumption that the effects of these influences can be "averaged out"[22] over a period of 10 to 20 years is questionable, given the irregularity of their occurrences.

As an example, it has been demonstrated that sunspot activity affects weather patterns on Earth and that sunspot cycles occur about

[22]Ferguson et al. (1986) and Dolezal (1982).

every eleven years (Akhromeiko, 1965). However, accurate prediction of weather events on a year-to-year, or even week-to-week, basis in a particular area remains elusive.[23]

Unless all sources of variation can be represented, models cannot be exactly specified, and their predictions become less amenable to tests of statistical reliability. Beyond the above, even if all the known factors which influence regeneration establishment could be appropriately quantified, there are probably influences on tree regeneration of which we are not yet aware. These cautions are not meant to deny the usefulness of predictive modelling, but to emphasize that its limitations must be understood.

[23]There is an excellent discussion of the unpredictability of weather in Chaos, by Gleick (1988).

CHAPTER 3

Stocking Measures

Trees Per Acre and Stocking Percent

Any study using regeneration survey data requires an understanding of a basic dilemma in the way stocking levels are commonly measured. The two parameters which are most commonly used are: 1. the average number of trees per acre (total number of trees tallied divided by the number of plots and multiplied by the reciprocal of the plot size), and 2. stocking percent (the proportion of plots stocked with one or more trees to the total number of plots, multiplied by 100). The dilemma is that neither measure by itself is complete in quantifying the stocking level of a stand.

Trees per acre (TPA) answers the question of how much regeneration there is, regardless of the plot size used, but tells nothing of the distribution of the trees (e.g., the trees could be growing in clumps or concentrated in one part of the stand). Stocking percent, on the other hand, indicates what proportion of the total area is growing trees, but does not provide an estimate of the actual number of trees on a site. Since tree counting may stop with the first tree found on each plot, less time in the field is needed to estimate stocking percent than TPA, but the stocking percent estimate is directly related to the plot size used (the larger the plot size, the more likely a tree will be in).[24]

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[24]A modification of the traditional method of computing stocking percent is to set a target number of trees per acre (e.g., 200) using a convenient plot size (e.g., 1/100 acre), and not count a plot as stocked unless it has at least a minimum number of trees per plot

(continued...)

Used in conjunction with each other, and based on a plot size which is related to the optimum growing space of a tree at a designated age, TPA and stocking percent can provide a meaningful estimation of stocking conditions, but alone each is insufficient. This is not a major problem in management, where both measures along with a specified plot size may be used to decide whether the regeneration is certifiable according to the silvicultural presciption. For the purposes of regression analysis in this study, however, I wanted a single quantitative dependent variable which could equate stocking results from surveys using different plot sizes, and which would indicate both the average density and distribution of stocking on regenerating stands.

There have been several attempts to expand on the measures of TPA and stocking percent; one approach is the use of formulas which convert the stocking percent calculated from one plot size into a comparable stocking percent from another plot size. Using data from surveys of reproduction stands in the white pine region, Wellner (1940) derived conversion curves based on the empirical relationship between the number of trees per acre (TPA) on milacre (1/1000 acre) and 4-milacre (1/250 acre) plots.

The converted stocking percent derived from the curves facilitated comparison of results calculated from surveys with different plot sizes. This was useful because for many years, the Forest Service had measured

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[24](...continued)
(e.g., 200 x 1/100 = 2 trees per plot). This measure is useful, but it has some limitations: it estimates the minimum, but not the actual number of trees per acre, and it is only expedient in field surveys when the desired number of trees per plot is an integer.

stocking using the smaller, more convenient milacre plot (defining the standard for satisfactory stocking as 40%) until it was reasoned that it would be better to use a plot size more closely related to the desired number of trees per acre and set the stocking standard higher. The ideal plot size was determined to be 4-milacres (1/250th acre) since in that area of the Northwest, 250 TPA represented the average number of dominant and codominant trees on fully stocked stands on average sites at rotation age. The stocking percent standard for this plot size was 65% (Wellner, 1940).

Wellner noted that because the curves represented average values, and large deviations from them were evident in the sample, it was appropriate to use the curves only for homogeneous areas of natural regeneration, 10 to 20 acres in size. The variation was attributed to sampling error and differences in spatial distribution. He suggested that they were not applicable to stands over 15 years in age because when stand closure occurs at or after that age, tree distribution becomes more even, and the curves would no longer be appropriate.

Grant (1951) described a different conversion method, in which a stocking percent derived from surveys using any plot size could be converted to a standardized plot size representing the ideal growing space for a tree within stands of similar species and site productivity.[25] Using this method, one could compare stocking surveys

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[25]This is essentially the same as representing the percent of a site's resources being used by seedlings. In some cases, ideal site use would be underestimated, e.g., if a non-stocked plot were surrounded by trees on its border using the light, moisture, and soil nutrients available from the plot opening. As McQuillan (1987) suggests, these circumstances would be balanced by others (e.g., the site use (continued...)

taken over time with different plot sizes. The formula he used to create the conversion equations was based on the binomial distribution.[26]

Grant's approach implicitly provides a measure of trees per acre (i.e., the stocking percent can be multiplied by the target TPA to arrive at the estimated number of well-distributed trees per acre).[27] However, it does not estimate the actual number of trees on the stand and thus does not address potential problems due to mortality (stocking levels might be less adversely affected by seedling mortality if there were many plots with more than one tree), nor does it identify the amount of excess trees for the purpose of planning pre-commercial thinning.[28]

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[25](...continued)
represented by a tree growing just inside a plot perimeter would be less than that represented by a tree at the plot center).

[26]A binomial distribution means that each plot would have an equal probability of being stocked as any other plot, resulting in a random distribution of seedlings. The conversion formula proposed by Grant is $y = 1 - (1 - x)^r$, where y is the converted stocking fraction, x is the stocking fraction for the original plot size, and r is the ratio of the size of the new plot to that of the original plot.

[27]The target TPA is derived from the plot size; i.e., 1/300 acre plots would indicate a target of 300 well-spaced trees per acre.

[28]Given a plot size of 1/300 acre and target of 300 well-spaced trees per acre (TPA), a stocking percent of 60% would not differentiate between the following situations: 180 TPA with one tree per stocked plot, 360 TPA with 2 trees per stocked plot, 1000 TPA with 20 or more trees in half the stocked plots and 1 tree per plot in the other half, and 300 TPA in a stocked area comprising 60% of the stand adjacent to a non-stocked area.

Spatial Patterns

One of the inherent problems of the stocking percent measures presented so far is they do not account for the tendency of trees on natural stands to grow in clumps, or in uneven spatial patterns. Trees, especially seedlings, rarely occur in either perfectly random or uniform distribution patterns;[29] instead, they are often spaced in clumps of varying sizes, due to seed supply and dispersal, the vigor of individual seedlings, and microsite variations such as duff depth, slash accumulation, and competition from brush and grass. The variation noted above by Wellner in his conversion equations was partially attributed to the uneven spatial pattern of trees throughout a stand.

Grant (1951) recognized this problem, noting that the premises of his conversion formula called for a random distribution of seedlings on stands with uniform site conditions and seed supply, whereas those conditions do not exist in nature. He suggested that the error introduced by this lack of correspondence between the premises and actual conditions would decrease as the area over which the conversion was applied decreased, since smaller areas are likely to be more homogenous.[30] He concluded by emphasizing that conversion results would be more accurate when the plot sizes were more equal.

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[29]A uniform distribution would be, for example, 8 by 8 foot spacing.

[30]By stratifying the plots from a survey into groups of plots and then calculating a weighted average of each group's converted stocking percents, Grant found the results to be closer to the actual stocking percent than conversions without stratification.

Fairweather (1984) explained how to create sets of decision curves for sequential sampling[31] using formulas based on two probability distributions, the Poisson and binomial.[32] He compared results from three types of surveys on five harvested units; two of the surveys were sequential samples which used Poisson-based and binomial-based decision curves, and one was a systematic sample. None of the sequential samples resulted in a misclassification (e.g., deciding a stand was adequately stocked when it was actually inadequately stocked), but on two of the stands no decision was reached after taking 150 milacre plots.

He cited several studies which demonstrated that in most cases, either the binomial or Poisson distribution would be appropriate for use

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[31]Instead of using a fixed sample size (e.g., one plot per acre), sequential sampling enables an examiner to take plots up to the point when a decision about adequate stocking can be made (by crossing either an "adequate" or "not adequate" decision curve), thus reducing the number of plots taken. This approach is useful in cases where the sole purpose of a survey is to qualitatively assess stocking, and the stand is either non-stocked or well-stocked.

However, if quantitative estimates were desired and/or the stocking was not clearly adequate or inadequate (i.e., the actual stocking percent was between the acceptable and unacceptable limits used to derive the decision curves), it would be necessary to use systematic sampling or a walk-through survey (both types of surveys are described in the next chapter). One major problem with sequential sampling is that even though it would reduce survey costs, the exam would likely not cover the entire area; if the stand was inadequately stocked or over stocked, a complete stand map as well as trees-per-acre estimates would be needed to write the treatment prescription.

[32]In the Poisson distribution, the random variable is the number of times an event occurs during a given unit of tmme or in a given unit of space, e.g., the number of seedlings occuring on a plot; the mean number of occurences per unit (M), is equal to the variance (V), or V/M = 1. In the binomial distribution, the random variable is the number of successes in *n* trials, e.g., the number of stocked plots in a survey; the mean is equal to n x p and a variance equal to n x p x q (where n equals the number of trials (plots), p is the probability of success on a single trial (plot), and q is 1-p). Formulas for both of the above probability distributions are given in Appendix J.

in systematic sampling (using the negative binomial distribution instead would allow the extent of clumpiness to be taken into account, but because of its complexity, he did not recommend it for general use). His results indicated that more plots would be necessary to arrive at a decision with Poisson-based curves than with binomial-based curves.[33]

To explore measurements of spatial patterns, McQuillan (1987) simulated regeneration samples on computer-generated stands exhibiting four different stocking patterns, each stand having an average of 300 trees per acre: a plantation with 12 x 12 spacing and 100% survival, a clumpy natural stand, a stand with trees located according to randomly generated coordinates, and a plantation with 10 x 10 spacing and 70% survival (mortality occurred randomly in this simulation). Each stand was sampled using two plot sizes, 1/300 and 1/100 acre, with 49 plots per sample.

In examining the simulated patterns, he applied a unique feature of the Poisson distribution, i.e., the variance equals the mean; his results reflected the concept, discussed in Grieg-Smith (1957) and Pielou (1974), that the variance/mean ratio (V/M) can be related to three distinct patterns of dispersion within stands:

1. When V/M is less than 1, the stand spatial pattern can be considered essentially uniform, as in the case of a plantation

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[33]The Poisson distribution is generally more appropriate when stocking levels have not reached the maximum level possible; if the trees are randomly distributed and near the maximum possible stocking level, the frequencies of different numbers of trees per plot will approximate a binomial distribution (Greig-Smith 1957).

(McQuillan's simulations of the plantation with 12 x 12 spacing had V/M ratios of exactly 0 for both plot sizes, and the plantation with 70% survival had V/M ratios of .574 and .546 for the 1/300 and 1/100 acre plot samples, respectively);

2. A stand with a perfectly random dispersion will have a V/M ratio close to 1[34] (the simulated samples had V/M ratios of 1.027 and .859);

3. If V/M is greater than 1, the stand is clumpy (most regenerating stands would reflect this condition); V/M ratios for 1/300 and 1/100 acre plot samples on the clumpy stand were, respectively, 2.784 and 3.113.

Although the V/M ratio was not used in any of the analyses of this study, it may be of interest to both researchers and managers as a measure of spatial patterns.

Effective Stocking

The main purpose of the explorations which led to the preceeding discussion was to find one single measure to use as a dependent variable in analyzing the survey data. An article by A.R. Stage, principal mensurationist at the Forest Sciences Lab in Moscow, ID, described a measure of stocking which was designed so that stocking standards for pole-size stands could be related to the standards for regeneration

[34] It should be noted that the converse is not necessarily true; a truly random pattern has other properties besides a V/M ratio nearly equal to 1 (Pielou, 1974).

(Stage, 1974). Until the last few years, only a few districts of USFS Region 6 were using this measure (Stage, 1987); it has recently been used on a trial basis by the Quinault Nation Dept. of Natural Resources (McQuillan, 1989).

The measure is similar to stocking percent, but has several features which make it more meaningful. First, it allows for different stocking level standards while using the same plot size. Conversely, it can also be used to analyze data obtained from surveys which used different plot sizes. By using a variation of the stocked plot method, with the Poisson distribution as a reference standard for uniformity, it recognizes that stands with a relatively uniform tree dispersion should rate higher in terms of effective stocking than those with clumpy dispersion.

Stage's measure also accounts for the fact that in well-stocked natural stands, 5 to 10% of the plots might be non-stocked when an average of three trees per plot are counted. Even in an exactly spaced plantation of 300 trees per acre, approximately 9 percent of 1/300 acre plots will be empty. The measure gives some "credit" for additional trees on a plot, but only up to a limit which depends on the desired stocking level; this limit prevents undue inflation of stocking from overly dense plots.

The procedure suggested by Stage (1974) for calculating this measure is outlined below. Appendix C shows the mathematical formulas and values used in his derivation, an example of how to calculate Stage's stocking percent, and a table comparing stocking percents and trees-per-acre estimates calculated from the traditional method with those calculated according to Stage's method.

Procedure for Calculating Effective Stocking (From Stage, 1974)

1. Determine the average number of trees per plot (TPP) needed to meet the stocking goal (call it the "target TPP"), e.g., if using 100th acre plots and the goal is 200 trees per acre, the target TPP would be 2 trees per plot; the suggested range of targets is 1.2 to 3.5 trees per plot.

2. Use the target TPP as the mean of a Poisson distribution (this agrees with a study by Persson (1973) which showed that after random thinning of plantations, the spatial dispersion approached the Poisson distribution).

3. Determine a set of stocking percentages for plots with i = 1, 2, 3, and 4 or more trees per plot such that if the percentages are multiplied by the corresponding Poisson probabilities for each i, the sum of the products will be 100 percent. This increases the stocking percentage attributed to each tree on stocked plots, and thus allows for some empty plots without underestimating stand stocking.[35]

4. To incorporate the emphasis on uniform distribution without entirely negating the effect of additional trees on a plot, assume that the second tree on the plot contributes two-thirds as much to the stocking as the first tree and that each additional tree represents two-thirds the stocking of the previous tree. This ratio is in close agreement with weights derived empirically in Staebler's study (1949) of

[35]Essentially, the probability for i = 0 trees per plot is distributed among the other i's.

stocking levels on Douglas-fir stands after 15 years of growth from various initial stocking levels.

5. Place an upper limit on the number of trees per plot which contribute to increased stocking; the limit suggested by Stage is the number of trees per plot that occurs with a probability of less than .3 in the Poisson distribution (see Appendix C for Stage's equations).

The application of this method in the field would be more expensive than the traditional stocked plot method, because the examiner would have to count more than one tree (if present) on each plot; however, it would be less expensive than the method used for estimating total TPA since the count may stop after 4 trees on a plot (for the range of 1.2 to 3.5 target trees per plot). The measure represents the percentage of a site's resources which would be used when the trees reach 5 inches in diameter (Stage, 1987), and provides a useful estimate for planning silvicultural treatments such as planting or thinning.

Like the other measures discussed above, it lacks spatial information about the locations and sizes of areas which are overstocked and understocked. Its usefulness for management purposes would thus be enhanced by a stand map showing those locations.

Although Stage's method initially appeared complex, it was easily applied to the data available for this study (it did require data entry from each of the plot surveys). To create a more meaningful estimate for foresters, who generally look at stocking levels in terms of trees per acre (TPA), the percentage can be multiplied by the prescribed TPA, resulting in an estimate of <u>effective</u> trees per acre (ETPA). ETPA is the dependent variable I used in the linear regression analyses described in Chapters 4, 7 and 8.

Desired Stocking Levels

One final point in this discussion of stocking measures is the implicit requirement of relating regeneration stocking targets to desired stocking levels of mature trees. One of the most difficult questions which silviculturists must respond to in their prescriptions is what stocking level of established regeneration will ultimately result in the desired trajectory of stand growth. There appear to be two general perspectives about this: one is that it is as undesirable to have more than a maximum number of trees per acre as it is to have less than a minimum at five years after harvest, since the thinning of excess trees adds to the cost of management.

The other perspective is that some amount of excess regeneration is desirable in order to allow for genetic gain through thinning, i.e., trees with phenotypic competitive dominance are best selectad during thinning if they have had the opportunity to compete with neighboring trees. In this view, the additional cost of removing excess trees would be compensated for by increased growth over the rotation (and in future rotations if the genetic gain were to continue).

An interesting paper by Harry (1986) addressed this second view, and described a method for calculating the number of lodgepole pine cones needed after a regeneration harvest to meet different stocking goals. One of the goals was 1800 trees per acre (TPA) by stand age 20 to allow for genetic gain through thinning to approximately 600 TPA since "research is showing best wood fiber and sawlog production at densities ranging from 400 to 700 TPA."[36]

The assumptions Harry made about interim stocking percents were based on a study of lodgepole pine ingrowth in Canada (Crossley, 1976), which determined that the trees-per-acre present at year 5 was 21.3% of that found at year 14 after site preparation. Assuming mortality would equal additional ingrowth between year 14 and year 20, Harry calculated that 383 trees per acre at year 5 after site prep would result in the desired goal of 1600 TPA at year 20.

Silvicultural prescriptions for stands with regeneration harvests on the Missoula Ranger District from 1980 through 1982 appeared to be congruent with this assumption that ingrowth of additional seedlings would exceed mortality over the first five to twenty years of a new stand, and that the ratio of ingrowth to mortality would likely vary according to site conditions, species composition and seed availability. The range for the prescribed minimum TPA for these stands was from 150 to 300 well-distributed trees per acre (minimum TPA prescriptions were generally higher for more productive sites, since better sites are able to support more trees per acre).[37]

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[36]The thinning guides suggested for the Lolo National Forest in Christopherson and Applegate (1987) are within this range for stands at age 20: 436 TPA for ponderosa pine, 538 TPA for Douglas-fir and larch, and 681 TPA for lodgepole pine.

[37]The prescriptions usually recommended a range of 200 to 600 well-distributed TPA, which indicated managerial limits, i.e., stands with less than the minimum TPA would require planting, and those with more than the maximum TPA would be considered future candidates for thinning.

In this study, I assumed that the silvicutural prescriptions for minimum stocking levels on harvested stands were appropriate for the site conditions and desired regeneration species. The main focus of the study was an examination of how long it takes for regeneration on the Missoula District to reach the prescribed levels.

CHAPTER 4

Methods

Area Description

The study stands are in four drainages on the Missoula District of the Lolo National Forest in western Montana: Lolo Creek, Deep Creek, Gold Creek and Greenough Creek (Fig.1). The soils are well-drained, gravelly sandy loams derived from Belt sedimentary parent material (Lolo National Forest, 1985), with ash layers of various depths (the most recent layer was deposited after the 1980 eruption of Mount St. Helens). Elevations of the study stands range from 4000 to 6400 feet. Over two-thirds of the 42 inches of annual average precipitation fall as snow, and nearly one half of the total precipitation becomes streamflow.

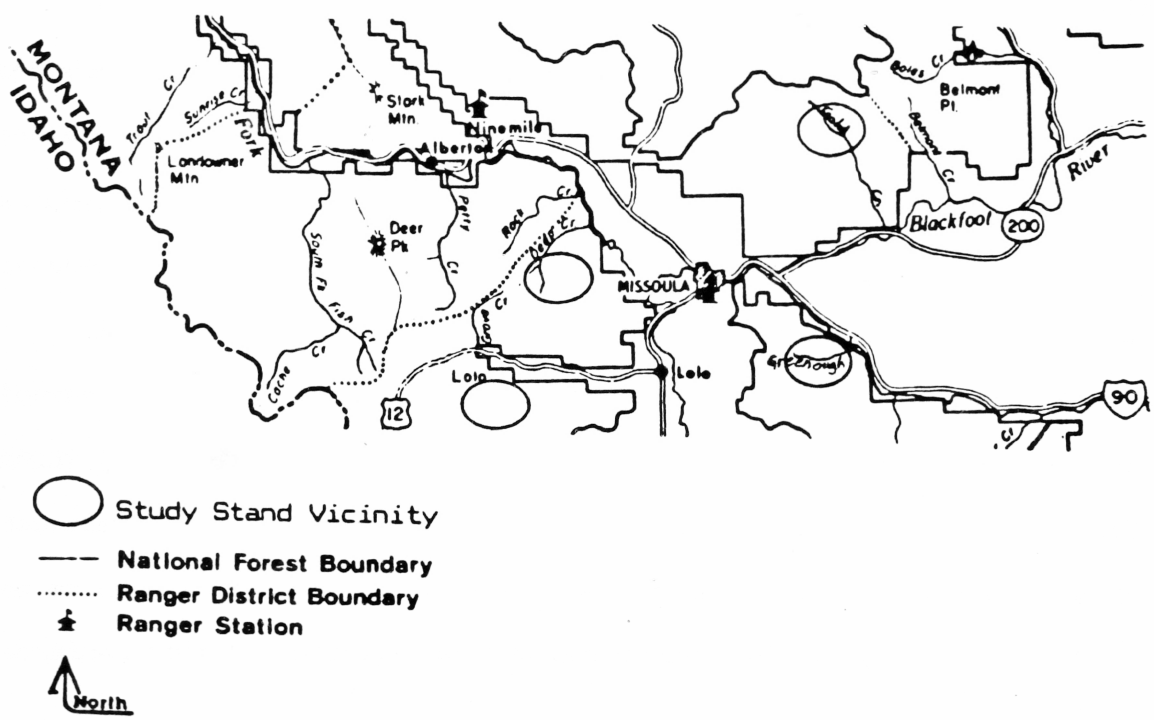

Figure 1. Area map showing general locations of study stands

Tree species found in the area include _Pinus ponderosa_, _Pinus contorta_, _Pseudotsuga menziesii_, _Abies grandis_, _Abies lasiocarpa_, _Picea engelmannii_, and _Larix occidentalis_. Forest habitat types, as defined in Pfister et al. (1977), are of the _Pseudotsuga menziesii_, _Abies grandis_ and _Abies lasiocarpa_ series and include types from Groups 2, 3, 4B, 4D and 5 of the Lolo Forest Habitat Type Groups (see Appendix A for a description of the habitat type groups).

Stand Selection

After a preliminary inquiry into the availability and uniformity of past regeneration exams,[38] stands harvested during the years 1980-1982 were selected for the following reasons:

1. By 1980, the National Forest Management Act (NFMA) had been in the statutes for more than three years, and agency regulations which reflected the directives of the NFMA had been in effect for over three months; presumably, the selected stands were harvested and subsequently treated in accordance with the NFMA and the 1979 regulations.

2. Also, by 1980, the Missoula District had developed a consistent format for regeneration surveys. Almost all of the surveys used in this study (1982-1988) were conducted by three people with several years of experience on the district.[39] Personal communication with them, as well as my own reconnaissance of 7% of the stands, convinced me that the data obtained from the surveys had few measurement errors.

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[38]A summary of this initial inquiry, encompassing stands harvested from 1965-1983, is in Appendix E.

[39]Frank Dugan, David Browder and Gary Lynam.

3. The Region 1 Reforestation Handbook suggested that the earliest regeneration could be considered established was after the seedlings had survived three growing seasons.[40] When the final stand selection for this study was made, at least three growing seasons had passed since the initiation of natural and/or planted regeneration on all of the stands harvested from 1980 through 1982.

In June 1988, I obtained a list of the 36 timber stands on the Missoula Ranger District which had regeneration harvests from 1980 through 1982 by querying the Forest Service Timber Stand Management and Record System (TSMRS).[41] These stands comprise the population of the areas on the Missoula District which were recorded at that time as having a regeneration harvest (clearcut, seed tree, or shelterwood cut) during the calendar years of 1980 through 1982.[42] They may also be considered a sample of those stands included in the District's timber base for which regeneration harvest treatments are recommended.

Data Sources

Forms 21 and 24 of the TSMRS contain stand site data, treatment activities, and treatment dates; the TSMRS forms were the main source of

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[40]Section 221, R-1 FSH 2409.26b 4/85 Amend 27 (see Footnote 45 for changes since 1985).

[41]See Appendix F for a description of the TSMRS query process.

[42] One stand was dropped from the initial stand list: 32203033, a 12-acre riparian stand with a habitat type of PSME/VACA, had a 1 acre seed tree cut in 1982 and a clearcut on another 5 acres in 1983. The stand maps included with the surveys of 1985 and 1987 did not clearly delineate the treatment boundaries, so the survey results were not used in the analyses. The six acres of harvested area were certified after a walk-through exam in 1987.

stand site and treatment data used in the analyses (after a field check of 7 percent of the stands, the entries appeared to be accurate). Site characteristics and activities of study stands are listed in Appendix D.

The plot data used to compute effective trees per acre (ETPA, as defined above at p.29 ff.), came from stocking survey reports which are maintained in stand folders at the Missoula Ranger District Office. These survey reports also provided sufficient information to indicate whether the regeneration was certifiable or not according to the stand prescription (see Appendix H for examples of survey reports).

Each survey report included stand maps which delineated areas of similar habitat types, aspects, types of treatment, and/or elevations. To facilitate analysis in this study, if a contiguous, clearly defined areas within a stand had values for site or management variables different from those recorded for the stand as a whole (the "parent stand"), the parent stand was divided into separate stands.

This resulted in 54 study stands, plus 7 parent stands which had at least one survey before being divided. If only part of a stand was harvested, then the activity acres, rather than the stand acres, were used for the independent variable of stand size.

Survey Description

The surveys consisted of two types, one using systematic sampling and the other being "walk-through" exams. In the first type, temporary fixed plots, 1/100 acre in size (11.78 ft. radius), were established along straight-line transects at intervals of 3 chains between plots so that the number of plots approximately equalled the number of acres being sampled (resulting in more or less a 1% sample, as recommended by Region 1).[43] As evidenced by the plot maps, transects were positioned so that elevation and topographic variations were sampled. Standard errors of the mean trees per acre ranged from 3 to 100% (standard errors for surveys with more than 10 plots did not exceed 40%).

On each plot, the height and species of seedlings were recorded, as well as whether they were planted or not. Ages and height growth were not recorded for any trees, nor was competition in terms of distance between trees considered. Advance regeneration (defined as seedlings and saplings already existing at the time of harvest) was not differentiated from that which began growing after the harvest, and was included in trees-per-acre calculations if it was non-cull.

Cull seedlings (which would probably not become crop trees due to excessive forking or dead tops) were recorded separately, as were residual trees (with DBH greater than 5 inches), and excess trees (any trees counted beyond six per plot). There were generally two estimates of trees per acre in the survey reports, one which included cull, excess and residual trees, and one which included only viable regeneration.

Microsite variables on each plot (i.e., slope, aspect, habitat

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[43]This type of systematic sampling is often used in forestry, in spite of the fact that it violates the principle of complete randomness, i.e., the location of a plot is not independent of the location of the previous plot. A discussion of the statistical implications of random and systematic sampling is in Appendix J. As long as plots are taken "as they fall," i.e., with no bias on the part of the examiner, systematic sampling is considered an acceptable sampling method for stocking level estimation.

Communication with the examiners who conducted the surveys used in this study convinced me that they understood and complied with the principle of not biasing plot location, even when plots landed in dense brush or nonstocked areas.

type, percent exposed mineral soil, residual tree canopy cover, and percent cover of grasses and shrubs) were not recorded, but references to inhibiting conditions were made in the remarks column. Distance to the nearest seed wall (stand of mature trees) was not measured.

Walk-through Exams

The second type of exam was the "walk-through," which relies on visual observation, rather than systematic sampling, to determine an estimated number of trees per acre, general seedling condition and distribution. Walk-throughs are useful since they save time and expense, and are justified when an examiner has had enough experience to make accurate judgements based on comparisons with past surveys.

Walk-through surveys are most often used when a stand is either clearly non-stocked or stocked, that is, as pre-treatment or certification exams, rather than for monitoring the progress of intermediately stocked stands. Twenty-four of the 54 study stands had at least one walk-through exam; on half of those stands, the results of the walk-throughs led to a decision to certify the regeneration.[44]

The use of walk-through exams is administratively expedient, but it created a problem in analyzing the study data since the values for the dependent variable of effective number of trees per acre could not be calculated for those surveys. However, to exclude walk-through exams from analysis because of their non-quantitative nature would create another, and more serious, problem in the determination of the rate at

[44]From the experience and conscientiousness of the examiners, I was convinced that their walk-through estimates were reasonable.

which stands become stocked, i.e., many of the later surveys, especially those taken on stands with certifiable regeneration, would not be included. Consequently, the qualitative results of walk-through exams (certifiable vs. non-certifiable) were included in two of the four data sets which are explained in more detail below (p. 44 ff.).

Paired Exams

Many stands had more than one plot survey during the study period. The increase of natural regeneration from one exam to the next on 25 stands averaged 26 effective trees per acre (ETPA); the periods between the paired exams ranged from 1 to 4 years, with a mean interval of 2.5 years. The decrease of planted regeneration on 13 stands averaged 45 ETPA, with a mean exam interval of 2 years. Paired sample t-tests, however, indicated these changes were not significant at the .05 level.

Stand-level vs. Plot-level Analyses

One benefit of this study is that it shows what kind of analyses are possible with the regeneration survey data available from the Forest Service. Since the microsite conditions (habitat type, vegetative cover, slope, aspect, site preparation method) of each plot were not recorded, the analyses are based on stand-level stocking rather than on the stocking of individual plots, the latter being the approach used by Ferguson, et al. (1986), Dolezal (1982), and Fiedler (1981, 1982).

Microsite conditions are a likely source of variation, affecting both the probability of a seedling becoming established and its survival and growth potential; thus, attributing the general microsite conditions of a stand to each plot within the stand, as was necessary in this study, results in a loss of information. On the other hand, the collection of plot-specific site data is very time consuming and of less use to a silviculturist than a general description of stand conditions, e.g., "dense brush on east side inhibiting seedlings," which would immediately indicate the existence and location of treatment opportunities.

An advantage of a stand-level analysis is that variation due to the location of a plot within a stand (as measured in terms of distance to a seed source as well as exposure to wind, light and heat) can be represented by the independent variable of stand size, i.e., as stand size increases, the boundary effects of seedfall, wind protection and shading decrease over the entire stand. Attempts to account for this variation in plot-level studies by measuring the distance to the closest seed wall have not been successful, because the associated variables of wind speed, wind direction, and seed fall timing and amount have not also been quantified.

One assumption in this study was that harvest areas, especially those which were not planted, had been located in such a way that adequate potential seed sources were available either inside or along the boundaries of the stand. Using 1987 aerial photographs, an examination of study stand locations relative to neighboring mature stands indicated that this was a valid assumption, at least in terms of adjacent mature stand cover; whether those trees had viable cone crops at any point after harvest of the study stands was not determined, nor was seed deposition measured.

Computer Software and Hardware

This project was expedited through the use of several different computer software packages. The MLIN program of the MSUSTAT statistical package, used for the multivariate linear regressions, was borrowed from the Montana Department of State Lands Division of Forestry. The LOGIT program of the SST statistical package, used for developing multivariate logistic probability models, was borrowed from the University of Montana School of Forestry. Stand data was obtained from queries of the U.S. Forest Service Timber Stand Management Record System (described above in Data Sources) on Data General computers routinely used by the Forest Service. Data analyses were performed on an IBM-compatible computer.

Data Sets

Of the four data sets which were derived from the surveys, there were two types: the first consisted of every plot exam taken on all of the stands, and was used in the linear regression models of effective trees per acre discussed in Chapters 7 and 8. The second type of data set consisted of both plot exams and walk-through surveys which were taken nearest to two points in time, five years after disturbance (harvest or site preparation) and seven years after harvest; this type of data set was used in the LOGIT models for certifiability, which are discussed in Chapter 9. The data sets and their corresponding dependent variables are shown in Table 1, followed by descriptions of the dependent and independent variables.

Table 1

Dependent Variables and Data Sets for Regression and Logit Models

Dependent variable	Regeneration Method: Natural only	Regeneration Method: Natural and Planted
Effective Trees per Acre-- Natural trees only on all plot exams (ETPA_NAT)	80 cases 1160 acres	-------- --------
Effective Trees per Acre-- Natural and Planted trees on all plot exams (ETPA_NAPL)	--------- ---------	80 cases 1160 acres
Certifiability by 5 years after disturbance on both plot and walk-through exams (CERT_5YR)	--------- ---------	39 cases 530 acres
Certifiability by 7 years after harvest on both plot and walk-through exams (CERT_7YR)	--------- ---------	45 cases 612 acres

Dependent Variables

The four dependent variables used in the analyses, ETPA_NAT, ETPA_NAPL, CERT_5YR and CERT_7YR, are defined as follows:

1. ETPA_NAT: effective stocking of natural regeneration only, a continuous variable calculated for all plot exams, based on prescription targets for certification; effective stocking (ETPA) is explained in Chapter 3 (p. 29 ff.), with calculations for ETPA shown in Appendix C.

2. ETPA_NAPL: effective stocking of both natural and planted regeneration; calculated in the same manner as ETPA_NAT, except that planted trees were included with natural seedlings.

3. CERT_5YR: certifiablity at five years after disturbance; a dichotomous variable based on whether the survey indicated that regeneration had met or exceeded <u>both</u> the prescribed TPA and stocking percent (calculated using traditional methods). CERT_5YR had the value of 1 if certifiable, 0 if not certifiable according to the survey results.

4. CERT_7YR: similar to CERT_5YR in all respects, except that the time frame for certifiability was seven years after harvest.

Natural and planted seedlings were differentiated during the plot surveys, so it was possible to separately analyze effective trees per acre (ETPA) of regeneration with and without planted trees for those exams; this separation is of interest because of the high cost of plantations in this area. However, because walk-through surveys usually did not differentiate between the two types of regeneration, and because certification of regeneration is based on the establishment of a prescribed number of well-spaced seedlings regardless of their source, certifiability was analyzed only in terms of combined natural and planted regeneration.

In calculating ETPA, only non-cull seedlings over 6 inches were included in the trees-per-plot counts. Although Region 1 stocking guidelines suggest height standards,[45] the prescriptions for the stands

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[45]Until 1988, the regional guidelines for certification suggested the following minimum heights for both natural and planted regeneration: 1.5 feet where competition from grass and shrubs is minimal, and 2.5 feet where competition is a factor and/or cattle grazing will be permitted after the regeneration is established (U.S.D.A. For. Ser., Reforestation Handbook Sec. 221 4/85 AMEND 27). In 1988, the height (continued...)

did not refer to a minimum height, requiring only that the seedlings be "established." Six inches is often used as the minimum height for counting seedlings in regeneration surveys since it indicates the seedling has survived at least one growing season, so it seemed reasonable for use in this study. Seedling condition was also considered: all stressed seedlings were counted and included in ETPA calculations, but natural and planted trees noted as having dead tops were not included in the calculations.

Another consideration in calculating ETPA was how to deal with non-stockable plots: if a plot was noted in the remarks as falling on rock or in standing water, it was excluded from the calculations; if it was noted as non-stockable due to competition from grass or brush, duff accumulation, and/or slash volume and density, the plot was included in ETPA calculations. This approach is consistent with Forest Service Region 1 guidelines.[46]

The values for the dependent variables, CERT_5YR and CERT_7YR, were determined according to the certifiability of a stand in terms of whether the trees-per-acre and stocking percent estimates from the latest surveys exceeded what had been prescribed. In most cases, stands which were assigned the value of 1 for the dependent variables also had

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[45](...continued)
limits were changed, but the criteria for certification were more definitive: 1. the required natural regeneration has survived at least three full growing seasons, is in healthy condition, and is a minimum of 6 inches high; 2. planted stock has survived at least two growing seasons and is in healthy condition (Ibid, Sec. 221 12/88 AMEND 36).

[46]U.S.D.A. Forest Service, 1985, Sec. 230, Reforestation Handbook (FSH 2409.26b).

been certified by the District; however, there were two stands which had been certified which were not certifiable on the basis of the original prescription, and conversely, two stands were certifiable but had not been certified after the last exam.

Dependent Variables Not Measured

Neither height growth nor species occurrence were used as dependent variables in any of the analyses. Height growth was not measured on the plots, so it could not be used as a variable. Species was recorded on the plot surveys for each tree, and species composition was occasionally estimated in the walk-through exams (e.g., "80% Doug-fir, 20% lodgepole"). Since the Regional guidelines state, "all native Northern Region conifers are acceptable species" (R-1 FSH 4/85 AMEND 27), species composition was not considered in this study, either as an independent or dependent variable. Most of the stands regenerated to the four early successional (shade-intolerant) species: Douglas-fir, larch, ponderosa and/or lodgepole pine. Only 3 out of the 54 study stands regenerated to predominantly subalpine fir (a shade-tolerant species which is not preferred in timber sales).

Sources of Variation-- Independent Variables

There were essentially two kinds of independent variables used in the models, those representing environmental variation and those reflecting managerial decisions. The first kind includes aspect, slope, elevation, and habitat type; the second includes acreage, number of residual trees, site preparation method, whether or not a stand was planted, type of planted seedling stock, type of planting crew, time between harvest and subsequent disturbance, time between disturbance and planting, times between harvest, disturbance, and planting and the survey.

The values for these variables were determined from TSMRS Forms (discussed above on page 38). The variables are described below, along with their code names, how they were quantified in the modelling process, and any related independent variables derived from them.

1. Aspect: the predominant aspect of a stand, including N, NW, NE, E, S, SE, SW, W and LR (LR = level or rolling; in the analyses, LR was considered the same as East). This variable was quantified as the sine (SINASP) and cosine (COSASP), computed from the radian measures of the aspects.

2. Slope: the average slope of a stand; coded as SLOPE, it was quantified in terms of slope percent * 100. SQRTSLOPE is the square root, and LNSLOPE is the natural logarithm of SLOPE.

3. Elevation: the average elevation of a stand, coded as ELEV and quantified in terms of feet above sea level divided by 100; ELEV2 was the squared term.

4. Habitat type: two groupings of habitat types (Pfister et al, 1977) were formed to create a dichotomous variable; the value of HABTYP was 0 if the predominant stand habitat type was in the Douglas-fir (PSME) series and 1 if in the subalpine fir (ABLA) series (there was only one stand in the grand fir (ABGR) series, and it was given a value of 1 for HABTYP, reflecting the moister, more productive conditions associated with sites in that series).

5. Stand size: the gross number of acres of treated area (consistent with Forest Service practices, gross acres were not reduced if non-stockable areas occured within the stand); coded as ACRES and quantified as an integer.

6. Number of residual trees per acre: this variable (coded as RESIDS) essentially reflects the type of harvest and was used instead of dummy variables for harvest type because it was more meaningful. Generally the number of residual trees per acre is 0 to 5 on clearcuts, 5 to 20 on seed tree cuts and 20 or more on shelterwood cuts. LNRESID, the natural logarithm of RESIDS, was also used in the modelling process.

7. Site preparation method: categorized as three dichotomous variables, SCAR, BURN and NONE; the value for SCAR was 1 if a stand had a mechanical scarification treatment after harvesting,and 0 if not; the value for BURN was 1 if a stand had a broadcast furn which covered most of the acreage, and 0 if not; and the value for NONE was 1 if no site preparation occurred after harvesting, and 0 if site preparation occured. Because of the "dummy variable trap," these variables were entered into regression equations either singly or with just one of the other site prep variables, but never all three simultaneously.[47]

[47]The "dummy variable trap" occurs when all of the dichotomous (dummy) variables which represent the possible values of a categorical variable, in this case site preparation, are included simultaneously in a model. The result is a singular matrix with a determinant of zero. To avoid this, one less than the total possible categories may be simultaneously included, with the effects of the non-included category being incorporated into the intercept (Koutsoyiannis, 1983).

8. Plantations: whether or not a stand was planted was represented by the dichotomous variable PLANTD, with a value of 1 if planted, 0 if not.

9. Type of planted seedling stock: the dichotomous variable PLUGS differentiated between container grown and bare root seedlings; it had the value of 1 if container stock, 0 if bare root or not planted.

10. Type of planting crew: the dichotomous variable CREW was used to differentiate between stands planted by contractors and those planted by Forest Service employees; it had a value of 1 if planting was done by Forest Service crews, and 0 if by contractor or not planted.

11. Time: all of the variables representing time are quantified as an integer value of the number of growing seasons which elapsed between activities, rather than simply subtracting activity dates from one another. A growing season was defined as 2 or more months between the months of May to August; for example, if a stand was harvested in June 1981 and scarified in October 1982, two growing seasons elapsed between the activities, and if a stand was burned in September 1983 and examined in May 1985, only one growing season elapsed between the two activities. For simplicity in the discussion of model results, the word "years" is used as the equivalent of growing seasons.

a. Time between harvest and survey: HARV_TO_EXAM is the code for this variable, and its related variables are LN_HARV_TO_EXAM (the natural logarithm of HARV_TO_EXAM), YREXHRV2 (the squared term), and YREXHRV3 (the cubed term of HARV_TO_EXAM).

b. Time between disturbance and survey: DIST_TO_EXAM is the code for this variable, with LN_DIST_TO_EXAM and DIST_TO_EXAM2 as the logarithmic and squared terms, respectively. If a stand did not have an additional site preparation treatment after the harvest, then DIST_TO_EXAM = HARV_TO_EXAM.

c. Time between harvest and disturbance: coded as HARV_TO_DIST; a value of zero for HARV_TO_DIST did not differentiate between those stands which never had a subsequent disturbance and those receiving a site preparation treatment immediately after harvest; however this did not seem to create a problem in this data set since the range of HARV_TO_DIST for cases with BURN = 1 was 1 to 3 years, and only one case out of the 30 which had values of 1 for SCAR had a value of 0 for HARV_TO_DIST.

d. Time between disturbance and planting: coded as DIST_TO_PLNT, this was the time between site preparation and the most recent planting, or if no site preparation occurred after harvesting, between the harvest and planting. DIST_TO_PLNT was equal to 0 if a stand was not planted.

e. Time between planting and exam: coded as PLNT_TO_EXAM, this variable represented the time between the most recent planting and the exam. Like DIST_TO_PLNT, it had a value of 0 if the stand was not planted.

12. Combined variables: several combined variables were created to represent interrelated effects between independent variables; one such variable, called THREE_VARS (rhymes with "three bears"), was significant in the two linear regression models:

THREE_VARS = COSASP * SQRTSLOPE * DIST_TO_EXAM.

The meaning of THREE_VARS will be explored in the discussion of model results in Chapters 7 and 8. Another combined variable, SLOPE*COSASP, represents the interactive effect described on page 15, and appears in one of the models discussed in Chapter 9.

Other interaction variables which were investigated but rejected during the modelling process include:

a. SINASP * SLOPE

b. COSASP * LNSLOPE

c. SINASP * LNSLOPE

Sources of Variation Not Measured

There are several sources of variation influencing regeneration which were not included in the models for various reasons, primarily because they were not measured on a stand-specific level: the amount and timing of seedfall and seedling germination; the amount and timing of precipitation and temperature for each stand; soil type; stand topographic position; percent cover of competing vegetation; percent exposed mineral soil; distribution of natural shading; seedling damage from cattle and rodents; seed predation by squirrels and birds; and additional operational factors in planting: stock condition, species, method used, survival, genetic selection. Weather and cone crops are discussed in detail in Chapter 6, but were not included as variables in any of the models because there were no quantitative measurements available on a stand-by-stand basis.

Unexplained variation usually exists in any kind of modelling, especially that related to biological processes. An underlying assumption in the models developed in this study was that the effects of the unexplained variation were distributed randomly throughout the stands and over time.

CHAPTER 5

Data Summaries

The data used to develop the linear regression and logistic probability models discussed in Chapters 7 through 9 are summarized in this chapter. Characteristics of individual stands are shown in more detail in Appendix D.

<u>Data Summaries for the Linear Regression Models of Effective Stocking</u>

Table 2 shows the means and ranges of the variables used in the two regression models for effective stocking (ETPA), including the means and ranges of the dependent variables, ETPA_NAT (ETPA of natural regeneration only) and ETPA_NAPL (ETPA of natural and planted regeneration). See Chapter 4 for variable descriptions.

Table 2

Means and Ranges of Variables
in the Regression Models for Effective Stocking
(Number of cases)

Variable	Mean	Range
ETPA_NAT for all cases (80)	96	0-300
ETPA_NAPL for all cases (80)	172	0-345
ETPA_NAT for AF habitat types (27)	115	18-300
ETPA_NAT for DF habitat types (53)	86	0-300
ETPA_NAPL for planted cases (43)	220	50-345
ETPA_NAT for unplanted cases (37)	117	0-300
Slope (%) for all cases (80)	36	8-70
Aspect for all cases (mode) (80)	NE	all but S and SW
Elevation (ft) for all cases (80)	5500	4000-6400
Years between harvest and exam (80)	3.8	2-8
Years between disturbance and exam (80)	5.2	1-7
Years between harvest and disturbance (80)	1.5	0-5
Years between dist. and planting (80)	1.0	0-6
Years between dist. and planting (43)	1.9	0-6
Years between planting and exam (43)	1.9	1-6

Figures 2a-2d summarize the frequencies of the 80 cases (surveys) by habitat type series and four other variables used in the analyses of effective trees-per-acre (ETPA). Not all of these variables appeared in the final regression models described in Chapters 7 and 8.

Fig. 2a Frequency of Cases in ETPA Models by Habitat Type and Aspect

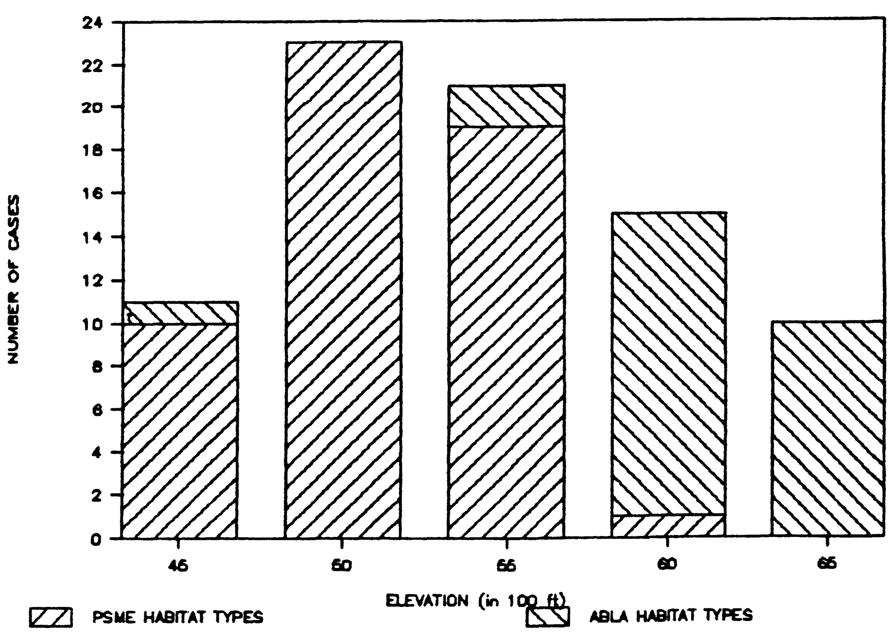

Fig. 2b Frequency of Cases in ETPA Models by Habitat Type and Elevation

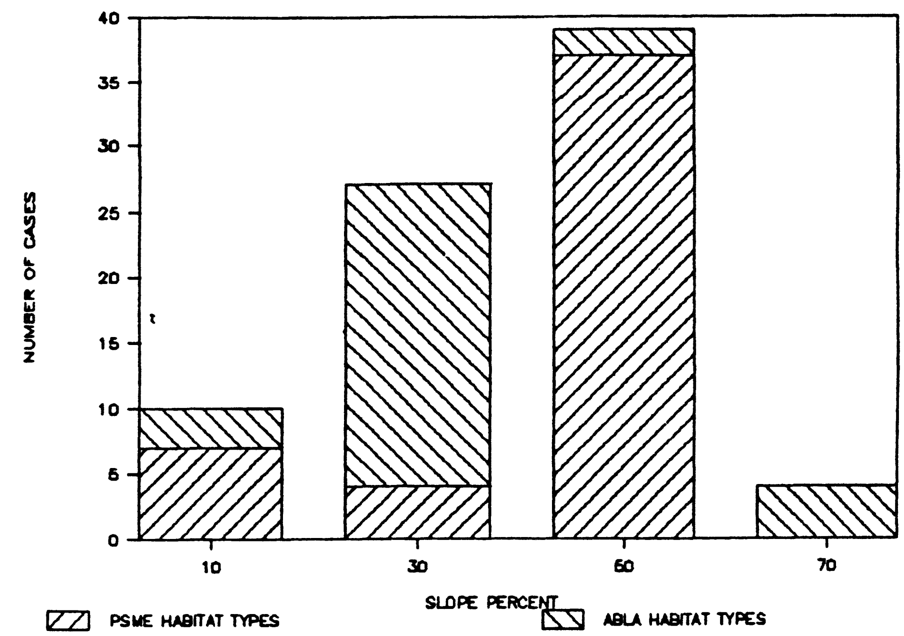

Fig. 2c Frequency of Cases in ETPA Models by Habitat Type and Slope

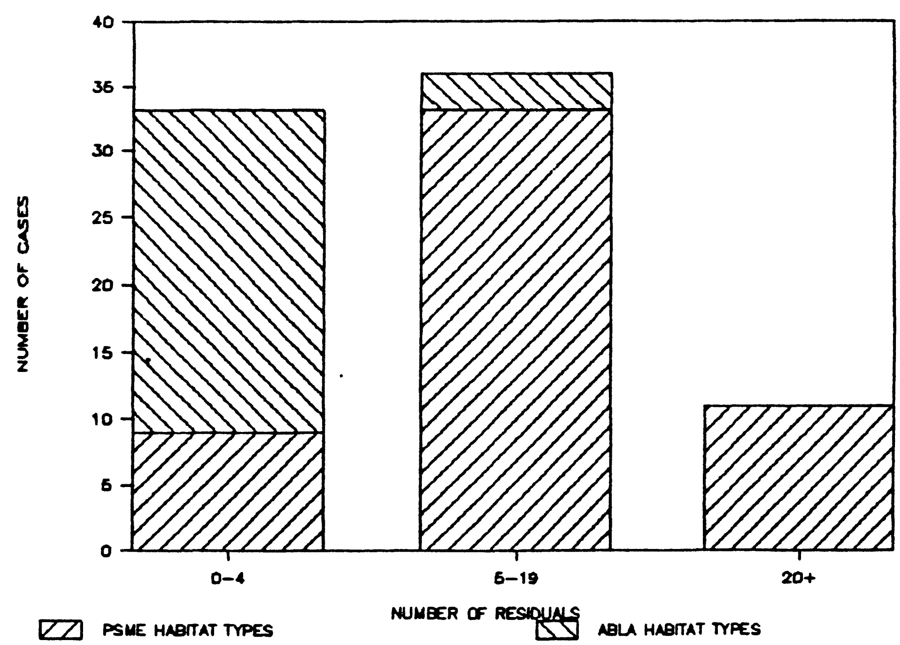

Fig. 2d Frequency of Cases in ETPA Models by Habitat Type and Residuals

<u>Data Summaries for Stands Used in Logistic Probability (LOGIT) Models</u>

The following histograms summarize some of the survey information (as of 10/89) on the stands considered in the two logistic probability (LOGIT) models, one for certifiability 5 years after disturbance (DIST5CERT), and one for certifiability 7 years after harvest (HARV7CERT).[48] The histogram categories represent the most significant variables from the two models. Figures 3a-3c show stand frequencies for DIST5CERT and Figures 4a-4c show stand frequencies for HARV7CERT.

Of the 39 stands whose data were analyzed in DIST5CERT, 15 were certifiable by the fifth year after disturbance and 24 were not certifiable; the proportion of certifiable stands is .39 with a 95% confidence interval of ± .153. Of the 45 stands analyzed in HARV7CERT, 20 were certifiable by the seventh year after harvest and 25 were not certifiable, a proportion of .44 ± .145 (95% confidence interval).

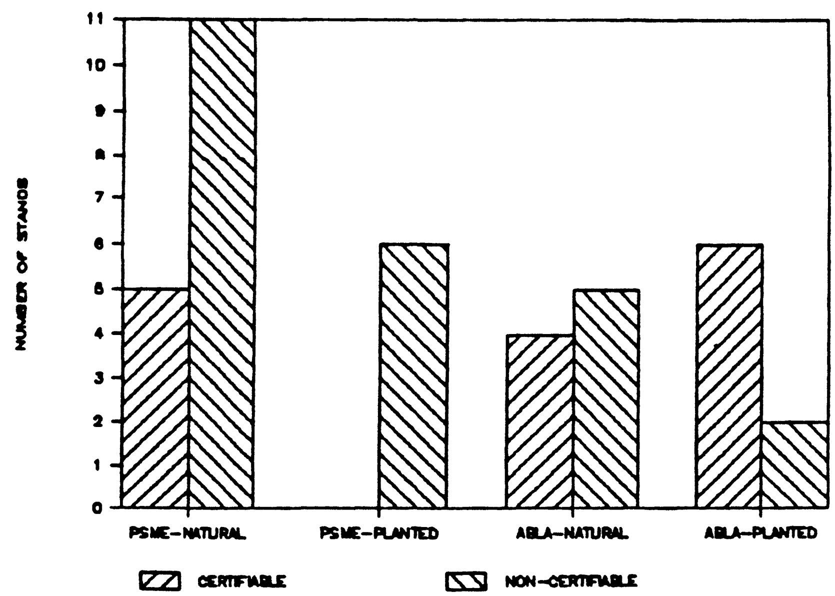

Fig.3a Frequency of Stands in DIST5CERT by Regeneration and Habitat Type

[48]The reasons for choosing these two time frames for the LOGIT models are discussed in Chapter 9.

Fig.3b Frequency of Stands in DIST5CERT by Elevation

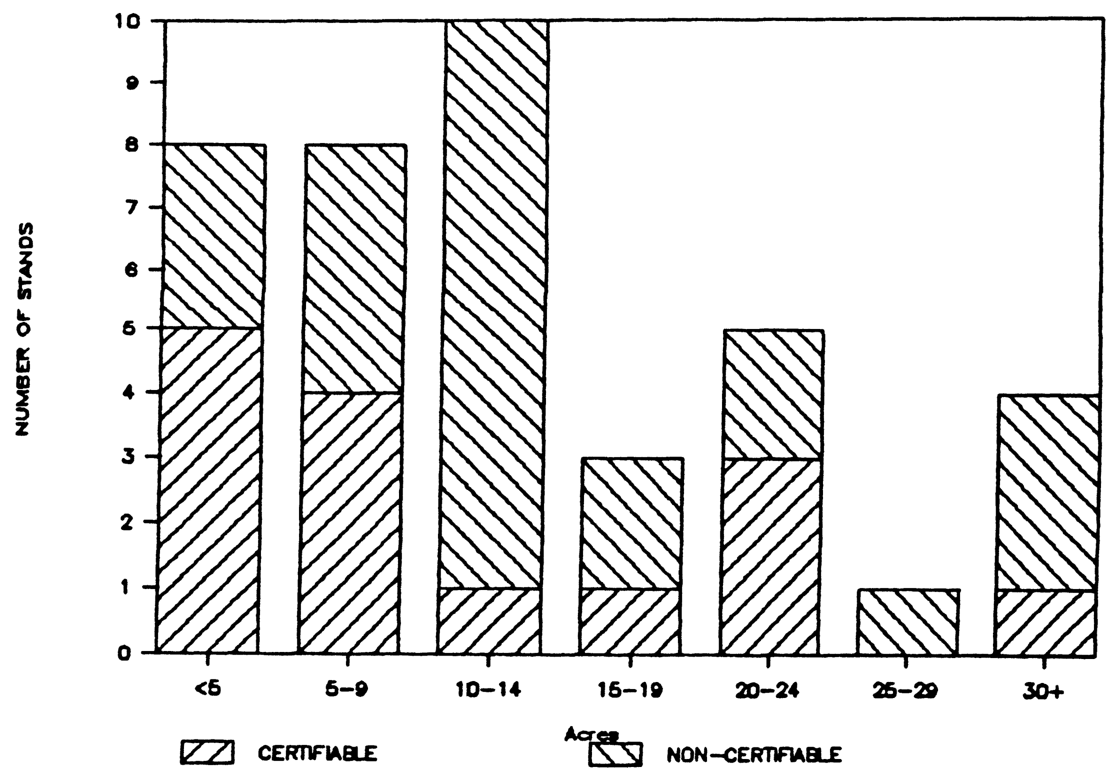

Fig.3c Frequency of Stands in DIST5CERT by Stand Size

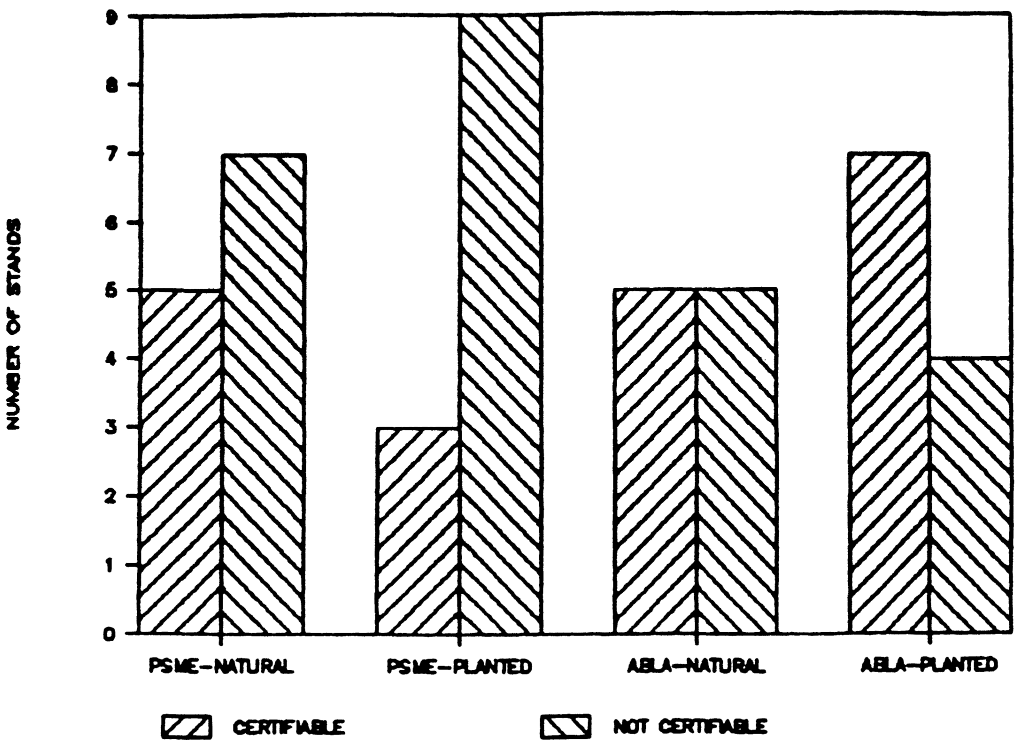

Fig.4a Frequency of Stands in HARV7CERT by Regeneration and Habitat Type

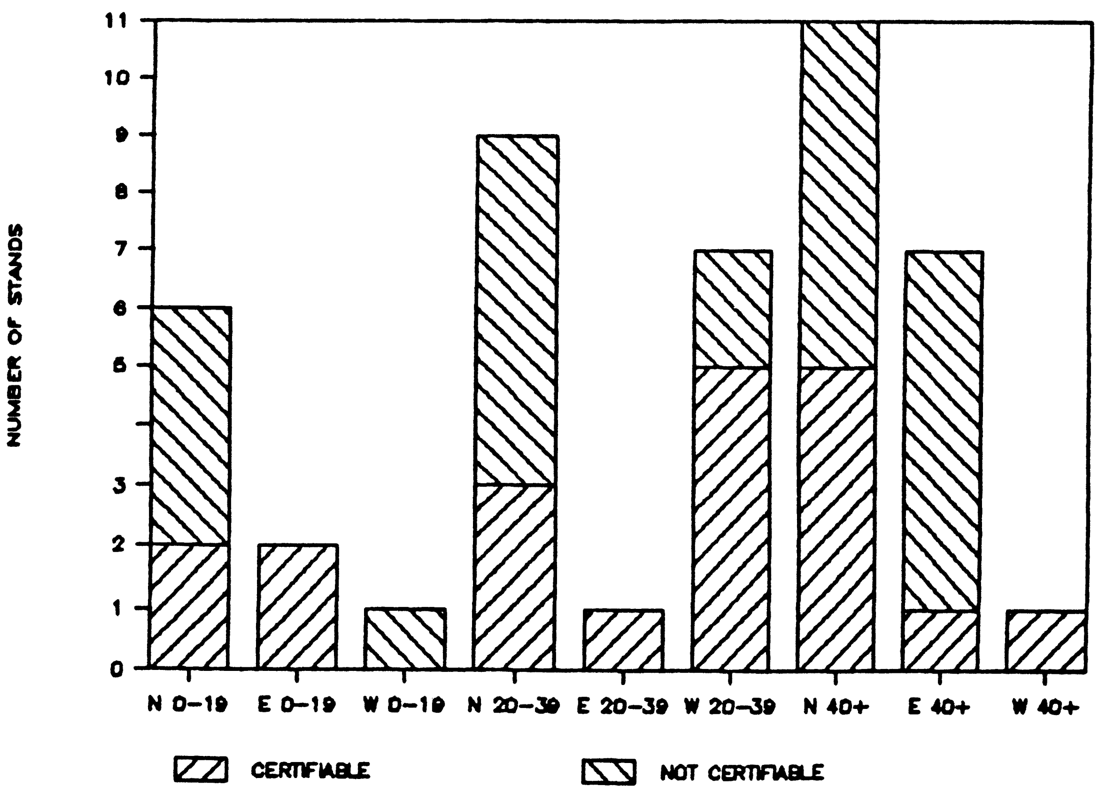

Fig.4b Frequency of Stands in HARV7CERT by Slope % and Aspect

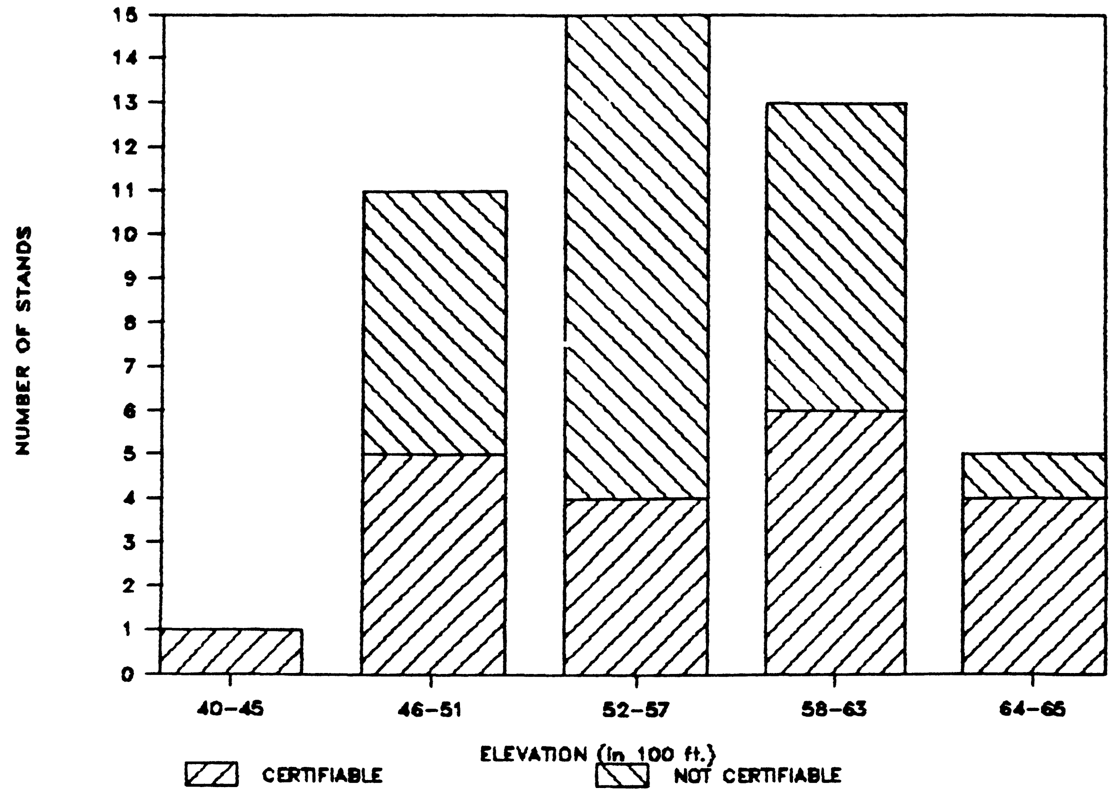

Fig.4c Frequency of Stands in HARV7CERT by Elevation

CHAPTER 6

WEATHER AND CONE CROPS

Weather Analysis

The temperatures to which trees are exposed and the amount of moisture available to them influence all phases of regeneration, from cone initiation and seed production to germination, survival and growth. A major problem encountered in this study was how to quantify the effects of temperature and precipitation on the study stands. Slope, aspect, elevation and habitat type are often used as variables in stand growth models to represent the relative effects of radiation and moisture on different sites, but they do not account for variation due to actual weather conditions.

The most direct way to obtain weather data is to record soil/air temperatures and moisture, humidity, and wind speed on a site at regular intervals. Since this was a retrospective study, and meteorological measurements were not taken on the harvest sites, site-specific weather records were not available.

Another way to quantify the effects of weather is to extrapolate stand-specific estimates from data collected at meteorological stations. Running (1982) described several such extrapolation methods, including area-averaging and regression models based on correlations between elevation and air temperature. Although temperature and precipitation data were available from local meteorological stations, I did not derive stand-specific estimates from them.

Instead, I used the station measurements (monthly average temperatures and total precipitation) to summarize the general weather conditions in the study area from 1980-1988, and to identify time periods in which departures from normal precipitation and temperatures may have influenced initiation, survival and growth of regeneration on the surveyed stands.[49] My assumption was that even though the weather data was not applicable to individual stands, the departures from normal would indicate, for the study area and time frame, weather conditions which might have promoted or delayed regeneration establishment.

Objectives

The three objectives of the weather data analysis were:

(1) To determine whether the means of monthly precipitation and temperatures for the 9-year period of 1980-1988 differed significantly from those during previous periods;

(2) To identify unusual weather conditions on the basis of departures from 30-year normal temperatures and precipitation;

(3) To examine weather data in conjunction with observations of cone crop intensities during 1978-1988 and make comparisons with correlations found in the literature between weather patterns and cone crop intensities.

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[49]Monthly average air temperature and total precipitation are useful in a relative way as indicators of potential seedling stress and survival. For example, if the monthly total precipitation for two successive months during the growing season was significantly lower than normal, and temperatures were significantly higher than normal, it is likely that either heat and/or evaporative demand would be excessive enough to cause some stress and mortality.

Weather Data

Monthly temperature and precipitation data examined in this study were compiled from National Oceanic and Atmospheric Administration Annual Summaries of Climatic Data for Montana (NOAA 1959-1988). Of the western Montana stations listed in the NOAA publications before 1985, Lolo Hot Springs (LHS) was the closest in proximity and elevation (4055 ft.) to the study areas. From 1967 to 1976, the LHS monthly records were complete; however, before and after those years, there were many missing values in the station's records, and in 1985, the LHS station was dropped from the NOAA summaries.

My search for a suitable station or group of stations whose data records were consistent from 1959 through 1988 involved comparisons of departure-from-normal data available for Lolo Hot Springs (LHS) with departure data listed for three stations near Missoula,[50] and for the Western Montana Division (which includes stations from Polebridge to Darby). Since departures from normal for the Western Montana Division from 1959 to 1985 were less different from the LHS departures than those for any single station in the vicinity, the Western Montana Division data was used in this study (see Appendix G for weather data tables).

Methods and Results

(1) General weather conditions (1980-1988)

Three periods were chosen for comparison with 1980-1988: 1971-1979, 1962-1970, and 1959-1988. The first two periods are the 9-year

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[50]Phillipsburg Ranger Station, Potomac, and Missoula 2 NE.

periods immediately preceeding the study years of 1980-1988. The years 1959-1988 were chosen for the comparison because those years comprise the 30-year period which included the study years.[51] See Appendix G for monthly temperature and precipitation data from 1959-1988.

The null hypothesis of the three pooled-sample t-tests was that there was no difference (significant at a 95% confidence level) between monthly means. For example, the hypothesis of the one-tailed tests for mean differences between January means from 1980-1988 and 1959-1988 was:

$$H_0: \mu_{Jan1959-88} - \mu_{Jan1980-88} = 0.$$

The monthly means, standard deviations and t-test results from these three two-sample comparisons are in Appendix G. Table 3 shows results for those months which had statistically significant differences at the 95% confidence level.

Table 3

Comparisons of 1980-1988 Weather with Three Other Periods
(for months with significant differences, 95% confidence level)

Monthly Total Precipitation

Period	January	May	June
1959-88	Drier*	-----**	-----**
1962-70	Drier	Wetter	-----**
1971-79	Drier	Wetter	Wetter

Monthly Average Temperature

Period	March	April	May
1959-88	Warmer	Warmer	Warmer
1962-70	Warmer	Warmer	Warmer
1971-79	-----**	-----**	Warmer

* 1980-88 was drier on the average than 1959-88, at .05 level
** difference was not significant at the .05 level

[51]The 30-year period is a conventional standard used by the NOAA as the sample size for calculating departure data.

The two most definitive results from this analysis were that on the average during 1980-1988, January was drier and May was warmer than in the three comparison periods. A drier January indicates a reduced snowpack, and a warmer May indicates increased evaporation following germination.[52] Warmer temperatures in March and April (the months preceeding germination) during 1980-1988 indicate earlier melting of the snowpack than during the earliest 9 years of the period 1959-1988. However, the warmer May temperatures and lower snowpack may have been offset by more precipitation in May (on the average) during 1980-1988 than in the two previous 9-year periods.

Because they represent period averages, these results are only general comparisons, but one important indication is that the period of 1980-1988 did not have a significantly droughtier growing season (May to September) than the three test periods. The next step in the analysis was to identify unusual weather conditions within individual years.

(2) Unusual Occurrences During Individual Years

In order to identify periods in which extreme and/or long-lasting weather occurences may have had an impact on regeneration rates within the years 1980-1988, monthly weather data from 1980 through October 1988 were compared with the 1959-1988 monthly means. Table 4 (next page) summarizes that analysis. There are two main considerations in

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[52] Maximum germination immediately following snowmelt is characteristic of most Rocky Mountain conifers (Blake, 1976). Snowmelt in the study area generally begins in the middle of April and is 10 to 50 percent complete by the end of the first week in May (NOAA, 1959-1988).

examining Table 4: one is the duration of significantly non-average weather from month to month, and the second is the combined effect of temperature and precipitation.

Table 4

Occurrences of Unusual Precipitation and Temperatures
(monthly data compared with 30-year averages of 1959-1988)

Year	Month	Precip.	Temp	Year	Month	Precip	Temp
1980	April	-----*	warmer**	1985	Sept.	much wetter	cooler
	May	very wet	warmer		Oct.	-----	cooler
	June	wetter	-----		Nov.	-----	very cold
	Dec.	wetter	warmer		Dec.	drier	cooler
1981	Jan.	drier	warmer	1986	Feb.	drier	-----
	May	much wetter	-----		March	-----	warmer
	June	wetter	cooler		May	-----	warmer
1982	Feb.	wetter	-----		June	-----	much warmer
	April	wetter	cooler		July	-----	warmer
1983	Jan.	-----	warmer		Aug.	-----	warmer
	Feb.	-----	warmer		Sept.	wetter	-----
	March	-----	warmer		Dec.	drier	-----
	July	much wetter	cooler	1987	Jan.	drier	-----
	Aug.	-----	warmer		March	wetter	-----
	Nov.	-----	warmer		April	drier	much warmer
	Dec.	-----	much cooler		May	-----	warmer
1984	Feb.	drier	warmer		June	-----	warmer
	March	-----	warmer		July	much wetter	-----
	April	wetter	-----		Aug.	-----	cooler
	Oct.	-----	cooler		Sept.	drier	-----
1985	Jan.	drier	-----		Oct.	drier	-----
	Feb.	-----	cooler		Nov.	drier	-----
	March	drier	-----	1988	April	-----	warmer
	May	-----	warmer		June	-----	warmer
	July	drier	much warmer		Aug.	drier	-----
	Aug.	wetter	-----		Oct.	-----	much warmer

* the monthly total or average was less than one standard deviation different from the 30-year average;

** warmer/cooler/wetter/drier = more than one standard deviation from the 30-year average;

much warmer/cooler/wetter/drier = more than two standard deviations;

very warm/cold/wet/dry = more than three standard deviations from the 30-year average.

From Table 4, I selected eight periods within the years 1980-88 which had potentially adverse or beneficial effects on regeneration; after examining all of the weather data, as well as snowpack statistics (NOAA 1959-1988), I made the following inferences:

1. May and June 1980- Mt. St. Helens erupted on May 18, 1980, creating considerable ashfall which had an immediate cooling effect in the study area. Over the next month, precipitation was higher than had ever been recorded for the month of May, and temperatures were somewhat modified (warmer in May and cooler in June), creating potentially favorable conditions for germination and seedling growth. A laboratory study by Stark and Essig (1985) found that the inch of ashfall probably caused no significant changes in the short-term soil fertility of ash-covered soil samples from three sites in western Montana, but that larch seedling growth may have been impeded, especially on nutrient-poor soil. It is possible that the increased rainfall may have been offset by an increase in above-surface evaporation due to the ash, but the ash could also have improved soil water retention. Thus, it is difficult to make any conclusions about the overall effect of the Mt. St. Helens ashfall on regeneration in the area.

2. May and June 1981- more rain than usual and cooler; probably beneficial to regeneration.

3. Spring 1982- increased snowpack due to cooler winter temperatures and more snow in the early spring; probably favorable since the increased snowpack would provide more insulation for seedlings and more soil mositure for germination.

4. Summer 1983- after a mild winter with a slightly lower snowpack, June and July had much more rain than usual and were cooler; potentially good growing conditions.

5. March through October 1985- slightly less than normal snowpack, drier and warmer growing season until August, wet and cool autumn, possibly unfavorable to new seedlings and favorable to established seedlings.

6. November 1985 through August 1986- cold and dry winter, warmer than usual spring, much warmer growing season, with normal precipitation; moisture stress indicated.

7. April through August 1987- low snowpack during the preceeding winter, drier in April and warmer during germination, possible mortality due to drought until July; the occurrence of heavy rains, followed by lower temperatures in August, was possibly favorable to established seedlings.

8. September 1987 through October 1988- dry fall, below normal snowpack, warmer spring, drier summer, and much warmer October; these conditions contributed to the worst fire season since 1910, and their cumulative effects were most likely detrimental to regeneration (however, the cone crop that fall was fairly good).

These eight periods indicate that weather conditions were more favorable for regeneration near the beginning of the decade, started to decline in 1985, and ended up being very droughty in 1988. This sequence of events might differ during any time period, but it does not appear to be an unusual cycle of weather conditions for western Montana

(3) The Weather-Cone Crop Connection

Several interesting studies have looked at the correlation between weather conditions and the periodicity of cone production at crucial times during the fruiting cycle of conifers (Eis, 1973; Van Vredenburch and la Bastide, 1969; Lowry, 1966). The main focus of these studies was on Douglas-fir cone production, but their methods and conclusions are applicable to other species as well. One prerequisite for this type of study is knowing the timing of specific events during the fruiting cycle. Table 5 summarizes this information for two species groups.

Table 5

Phenology of Seed Production in Common Conifer Species
(after Daniel, Helms and Baker, 1979)

	Season	Most pines	Douglas-fir, true fir, spruce
Year 0	Spring Summer	Initiation and differentiation of bud primordia	Initiation and differentiation of bud primordia
	Autumn Winter	(Dormancy)	(Dormancy)
Year 1	Spring	Cones visible Scales open Pollination	Cones visible Scales open Pollination
	Summer	Scales close, pollen tube is dormant	Fertilization Cone growth Seeds ripen and fall
	Autumn Winter	(Dormancy)	
Year 2	Spring	Growth of pollen tubes and cones Fertilization	
	Summer	Cones grow to maximum size; Seeds ripen,	
	Autumn	and fall	

It is evident from Table 5 that weather might influence cone and seed production at many points during the cycle. I have summarized the results of the studies by Eis, Van Vredenburch and la Bastide, and Lowry in Table 6. Only those results which were statistically significant at the 95% level are included.

Table 6

Summary of Relationships between Weather Conditions and Good Douglas-fir Cone Crops

<u>Year -1</u> (one year before differentiation of flower primordia)
Summer: cool July (Lowry); cool and cloudy June and July (Van Vredenburch and la Batiste (VVlaB)); not hot and dry during June, July and August (Eis)

<u>Year 0</u> (bud initiation and primordia differentiation in summer)
Winter: cool, sunny Dec., Jan. and Feb. (Eis); dry Jan. (Eis, Lowry)
Spring: moist and cloudy in March and April (VVlaB, Lowry), moist and cloudy April (Eis)
Summer: warm, sunny June (Eis); warm and dry June and July (VVlaB)

<u>Year 1</u> (pollination, fertilization, seed ripenijg and dispersal)
Winter: warm January (Lowry, Eis)
Spring: dry, sunny April (Lowry, Eis)
Summer: warm June (Lowry)

The authors cited in Table 6 discussed several possible mechanisms for the relationships they found between weather and cone development. The consensus for the hypothesis that a cool, cloudy July in the year before bud initiation and differentiation has a positive effect on cone production was that hot and dry conditions would impede photosynthesis, which has a long-term effect on the ability of a tree to create and sustain bud primordia.

Eis hypothesized that the benefit of a warm January in Year 1 could be due to the absence of frost damage and wind breakage. He also pointed out that a cool dry January indicates higher light intensity in addition to the direct temperature effect, but he was unable to define the actual physiological mechanisms which might be involved.

The positive relationship with a cool, moist April in Year 0 was statistically significant in all three studies, but each study had a different explanation: Lowry suggested a light intensity effect, Eis noticed that a higher proportion of strobili buds differentiated when not subjected to dessication, and Van Vredenburch and la Batiste conjectured that additional moisture availability removes or reduces the concentration of inhibiting substances and promotes the translocation of hormones and photosynthates.

According to Daniel, Helms and Baker (1979), above-average cone crops for pine species generally appear to be associated with unusually warm, dry conditions at the time of primordia initiation (27 months before cone maturation) and unusually high rainfall at the time of flowering (15 to 18 months before cone maturation). Because the length of the pine fruiting cycle is three years (instead of two for most conifers), there are more opportunities for external influences on cone pvoduction; this is one reason for the infrequency of good cone crops from ponderosa pine, but it does not explain why lodgepole pine often has good crops two or more years in a row.

An important finding from these studies is that good crop years rarely occur twice in a row, since the sequence of a warm and dry summer following a cool, cloudy one cannot happen in consecutive years. The implications of this type of information for timber management are important, and there is a need for further research to substantiate the relationships between cone crops and weather.

Study Area Weather and Cone Crop Relationships

A formal statistical study of the relationship between weather and cone crops in this study would be a thesis in itself. Instead, I compared cone crop intensities observed in the study area from 1978 through 1988 (Table 7) with those predicted by the above studies (the predictions were based on average monthly weather indices for the area).

A list of cone crop intensities for the years 1967 to 1986 was provided by Ray Shearer, Research Forester, Intermountain Research Station, Missoula. The cone crops were subjectively determined from observations of the general area encompassing the locations included in this study; they are not site-specific, and reflect primarily Douglas-fir cone crops. The intensities were independently corroborated by Gary Lynam, Regeneration Forester on the Missoula Ranger District, and the list was expanded with personal observations made during 1987 and 1988 (see Table 7).

Table 7

Cone Crop Intensities in the Vicinity of Missoula, MT, 1967 to 1988

Year	Intensity	Code	Year	Intensity	Code
1967	Fair	0	1978	Good	1
1968	Poor	-1	1979	Poor	-1
1969	Poor	-1	1980	Good*	1
1970	Poor	-1	1981	Poor	-1
1971	Good*	1	1982	Fair	0
1972	Poor	-1	1983	Poor	-1
1973	Poor	-1	1984	Fair	0
1974	Fair	0	1985	Good	1
1975	Poor	-1	1986	Poor	-1
1976	Fair	0	1987	Fair	0
1977	Poor	-1	1988	Good	1

(* very good)

Table 8 shows indices created from the monthly weather data (NOAA, 1978-1988) in conjunction with information from Table 6: if the combined temperature and precipitation matched the weather condition for the corresponding year and season in Table 6, it was considered a positive effect on the cone crop for that year and the index was labelled "+"; if it was the opposite or significantly different from the condition in Table 6, it was labelled "-"; and if the weather conditions were not significantly different or appeared to cancel out within a season, the index was a zero. The codes for predicted cone crops are

Table 8

Comparison of Predicted with Observed Douglas-fir Cone Crops

	Weather indices								
Crop	Year -1*	Year 0*			Year 1*			Cone Crop	
Year	Summer	Win	Spr	Sum	Win	Spr	Sum	Pred.	Obs.
1978	+**	+	0	+	+	0	0	1***	1
1979	0	+	-	0	-	-	+	0	-1
1980	+	+	0	+	-	+	0	1	1
1981	-	0	-	-	+	0	-	-1	-1
1982	+	0	-	-	0	-	+	0	0
1983	0	0	+	-	+	0	0	0	-1
1984	0	0	0	-	+	-	0	0	0
1985	+	0	+	+	0	+	0	1	1
1986	0	+	-	+	0	0	+	1	-1
1987	-	0	-	0	0	+	+	0	0
1988	0	+	0	-	0	+	+	1	1

*Year -1 is two years before the crop year
Year 0 is one year before the crop year
Year 1 is the crop year

** + = positive effect of weather on cone crop
- = negative effect
0 = neutral effect

*** 1 = good cone crop
0 = fair cone crop
-1 = poor cone crop

the same as for observed cone crop intensities in Table 7, and were determined by averaging the indices. For simplicity, I considered only Douglas-fir cone crops.[53]

It appears from Table 8 that the predicted cone crops correspond fairly closely with those observed in the vicinity of the study area, especially the predictions of good and fair crops. The implications of these results for management are addressed in Chapter 10.

One final note is that I made no attempt to account for the loss of cones and seeds to disease, insects, rodents, frost or genetic incompatability. These are important factors in determining rates of regeneration establishment, but there were no data available for them [54]

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[53] The cone cycle for ponderosa pine is about one good crop every 7 years and for western larch, one fair to good crop every 3 to 5 years; lodgepole pine seldom has a poor cone crop and often has several good crops over successive years (Boe, 1954).

[54] There were two notable events which likely had damaging effects on cone survival; a heavy spruce budworm infestation in 1980 and cone killing frosts in the autumn of 1985 (personal communication with Ray Shearer, 1987). Neither of these are unusual within a 30-year cycle.

CHAPTER 7

Summary and Interpretation of the Regression Model for Effective Stocking of Natural Regeneration (NATMOD)

Regression Models for Effective Stocking

Two multilinear regression equations were developed from 80 systematic plot surveys taken on stands harvested from 1980 to 1982 on the Missoula Ranger District. The dependent variable in both models was the number of effective trees per acre, ETPA (see p.29 ff), which was regressed on several independent variables (described in Chapter 4). In the first model, called NATMOD, the dependent variable (ETPA_NAT) included natural regeneration only.

The second regression model developed in this study was NAPLMOD, with the dependent variable of effective trees per acre including both natural and planted seedlings (ETPA_NAPL). NAPLMOD is discussed in Chapter 8.

Summary of NATMOD

Table 9 (next page) shows the coefficients and associated statistics for NATMOD. There are several characteristics of the model which are immediately apparent: the first is that the *R*-squared value is relatively low, and indicates that only about half of the variation is accounted for by the variables in the equation. Considering the many influences on regeneration which were not measured, it is interesting that the *R*-squared is as high as it is. The *F*-ratio is not high, but indicates the null hypothesis that the coefficients of the independent variables are equal to zero can be rejected at the .01 level, i.e., at least one of the model coefficients has a non-zero value.

Table 9

Summary of NATMOD

Variable	Meaning	Mean	Coefficient	T-stat
ETPA_NAT	dependent variable	95.7	---	---
INTERCPT	intercept of equation	---	-1937.4	-2.907[1]
ELEV	stand elevation (100 ft)	55	76.675	3.000[1]
ELEV2	stand elevation squared	3025	-.73978	-3.024[1]
BURN	= 1 if broadcast burned, 0 if not	.31	-66.233	-3.906[1]
HABTYP	= 1 if ABLA or ABGR habitat type series, 0 if not (PSME series)	.34	72.614	2.232[2]
DIST_TO_EXAM2	squared term of DIST_TO_EXAM, years between last disturbance and exam	16.8	2.7297	4.954[1]
THREE_VARS	a multiplicative term: COSASP (cosine of stand aspect) * SQRTSLOPE (square root of SLOPE) * DIST_TO_EXAM (yrs between disturbance and exam)	6.8	1.1745	2.726[1]
HARV_TO_DIST	years between harvest and disturbance	1.5	14.652	2.798[1]

R-squared:	.533	Significance of coefficients
Corrected R-squared:	.487	[1] significant at .01 level
F-ratio:	11.72	[2] significant at .05 level

All of the variables in NATMOD except HABTYP were significant at the .01 level (i.e., the null hypothesis that their coefficients were equal to zero was not rejected at that level). HABTYP was significant at the .05 level, and was included because it contributed to the R-squared as well as to the meaning of the model. The variables of NATMOD, as well as some which were not included in the final model, are discussed in detail below (p.80 ff.), after a brief digression on a problem encountered during the analysis, and some general comments on model development.

Autocorrelation

One of the assumptions of ordinary least squares (OLS) regression is that successive values of the stochastic error term[55] are temporally independent, i.e., the value assumed by the error term in any one time period is independent from the value it had in any previous period. If this assumption of independence is not satisfied, there is autocorrelation of the error term (Koutsoyiannis, 1983). Because the data sets for both NATMOD and NAPLMOD included results from exams taken on the same stands at different times, autocorrelation was presumed to exist in the two regression models.

There are two potential results of autocorrelation: one is that variances of the parameter estimates from ordinary least squares (OLS) are likely to be larger than those obtained from other statistical methods; the other is that the variance of the error term is likely to be underestimated. Consequently, predictions based on the OLS estimates will not have the least possible variance (Koutsoyiannis, 1983).

One test for coefficient variance is to assign an accuracy interval around coefficients obtained from repeated regression runs using randomly selected subsets of the data at each replication. This

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[55]The stochastic error term is the random variable which represents unexplained variation in a regression equation; it is estimated by the residuals (deviations of observed values from the regression line).

technique is called a bootstrap analysis, and its use in this study is described in more detail in Appendix J.[56]

The results of the bootstrap analysis indicated the variances of two of the coefficients, BURN and HABTYP in NATMOD, were unstable due to autocorrelation. After re-evaluating the model with the bootstrap coefficients, I decided the effects of autocorrelation did not warrant corrective measures; in the absence of autocorrelation, the coefficients of BURN and HABTYP would not have such a strong influence in the model, but would have retained their signs and remained significant.

Model Development

The process of developing a statistical model involves several steps. First, the outliers (cases with large deviations of predicted from observed values) were examined closely to make sure the residuals were not due to errors in data collection or entry. The examination resulted in some data input corrections, but no outliers were removed.

Secondly, an analyst has the choice of which variables to include in a model, based on three criteria: the statistical significance of the coefficients; the contribution of the variables to the overall significance of the equation and explanatory value of the model (determined from the *F*-value and *R*-squared statistic, respectively); and whether the model reflects known biological relationships.

As an example, PLANTD (the dichotomous variable of whether or not

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[56]The Durbin-Watson test is often used to detect autocorrelation in time series data. It was not an appropriate test in this case because not all of the stands had multiple exams and because the successive exams were taken at irregular intervals.

a stand had been planted) was not included in the final version of NATMOD, even though when it was introduced into the model, its negative coefficient was significant at the .05 level, and the corrected *R*-squared increased to .535 (the *F*-value went down slightly to 11.10). Since most stands are planted when low stocking of natural regeneration is anticipated or is evident, and the process of planting causes minor, if any, damage to natural seedlings, the negative effect of PLANTD represented an external managerial decision rather than a direct influence on the natural regeneration itself; thus, PLANTD was not useful for predicting stocking levels or rates of natural regeneration.

Third, interactive regression packages, like the one used in this study, allow screening of variables on the basis of their significance and contribution to the *R*-squared value, giving instant feedback on how the variables interact with each other; this facilitates the generation of many different models. In comparing preliminary models with the final versions of both NATMOD and NAPLMOD, I noticed that predicted values of the dependent variable were similar, regardless of which independent variables were selected for the model. Thus, the data essentially "speak for themselves;" the most interesting part of the modeling process is the interpretation of model results.

Effects of Independent Variables in NATMOD

The coefficient for BURN was the most statistically significant in the model besides that for DIST_TO_EXAM2 (which is discussed below). The negative effect of BURN in the model is interesting because one might expect broadcast burning to benefit seedling establishment by reducing vegetative competition, duff depth, and slash (the woody debris left on a harvest unit). There are several possible explanations for the negative effect of BURN in NATMOD, none of which are definitive without knowing the severity of the burns or having estimates of post-burn slash volumes, exposed mineral soil and vegetative cover.

Broadcast burns are often used to reduce slash volume when equipment used in mechanical site preparation and slash reduction cannot be safely operated on steep slopes. Burning has varying effects on competing vegetation, depending on the intensity of the burn and type of vegetation; e.g., a moderate burn tends to stimulate regrowth of dense sod. A hot burn might reduce slash volume so much that little shade remains on the ground, and by blackening the soil, increase surface temperatures and evaporation.

Slash burning can also kill the residual trees which are left for shading and as a seed source. Standing dead trees (snags) provide some shade, and may also disperse seed (in the autumn following a burn, or at any time with serotinous lodgepole pine cones). However, the snags will become increasingly susceptible to disease and windthrow. Other effects of fire on regeneration include cone and seed destruction, loss of beneficial mycorrhizae, and/or mortality of existing seedlings.

In the NATMOD data, all but five of the cases with BURN = 1 had observed ETPA_NAT values of less than 100 effective trees per acre, and 15 of the 25 cases had ETPA_NAT values of less than 50, so the negative effect of BURN in this model on natural regeneration stocking is not spurious. All of the 25 cases which had a value of 1 for BURN were stands with habitat types in the PSME series on slopes over 35 percent.

Only 7 of the 25 cases had a southeast aspect, with an average ETPA_NAT of 32; the rest were on north, northeast and east aspects, with an average of 61 effective trees per acre for those cases.[57]

The variables which were most correlated with BURN in NATMOD were HABTYPE and THREE_VARS (the interaction term of aspect, slope and time). When BURN was excluded from the model, neither HABTYPE nor THREE_VARS increased in significance, indicating that with this data set, the effects of BURN extend beyond its correlation with habitat type, aspect, slope and time. Figure 5 shows the effects over time of BURN on predicted ETPA_NAT by aspect, with the other variables held constant (the average slope for the burned stands was 50%).

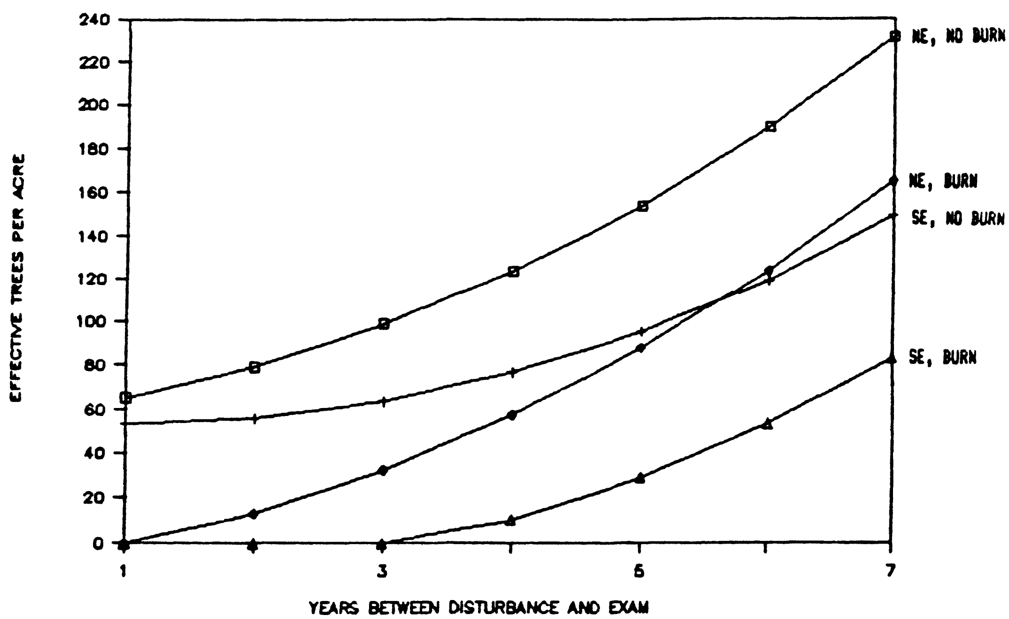

Figure 5 ETPA_NAT by BURN, Aspect and Time (PSME Habitat Types, 50% slope, 5500 ft., 1 year beteen harvest and disturbance, cosine of NE and NW = .7071, cosine of SE and SW = -.7071)

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[57]When NATMOD was evaluated using the bootstrap coefficient for BURN (either the median or the mean), the model predicted 14 additional effective trees per acre, *ceteris paribus*.

Looking at survey comments about burns was informative. On a stand which had two successive plot exams, the examiner noted, "stocked area unburned." Another stand, which had four plot exams, had the comment "burn killed seed trees." A third stand, which was eventually planted, lost residual trees due to a broadcast burn. An informal study by District personnel of natural and planted regeneration on a fourth stand indicated that the burn treatment (which occurred three growing seasons after the harvest) appeared to have killed most of the natural regeneration but benefitted the larch seedlings planted on experimental plots after the burn.

In this study, 20 of the 25 cases with BURN = 1 were stands which had been planted after burning; most of the plantations appeared to be successful on the basis of observed values for effective trees-per-acre of combined natural and planted seedlings (ETPA_NAPL). Many of these stands had Douglas-fir mistletoe infection, and had been planted with ponderosa pine and larch seedlings. If Douglas-fir natural regeneration was in fact inhibited by burning, the result would be healthier reproduction on those stands.

It would be premature to conclude from the model that broadcast burning inhibits natural regeneration, since it is not known what would have happened from no-burn treatments on the same sites. The strongly negative and significant coefficient for BURN in this model does indicate that alternatives to burning on dry sites should be considered, especially if the prescription does not include planting. Results from other studies also suggest the need for careful timing and application of burning, especially if residual trees are present.[58]

The most significant variables besides BURN and DIST_TO_EXAM2, were ELEV and its squared term, ELEV2. When all other variables were held constant, the combined effect of the negative coefficient for ELEV2 and the positive coefficient for ELEV created a downward parabolic curve (with ETPA_NAT on the Y-axis and ELEV on the X-axis) which peaked at about 5200 feet. Given the range of elevations in the data from 4000 to 6400 feet, it is not unlikely that, *ceteris paribus*, stocking levels would be higher at the mid-elevations since lower elevations receive less precipitation, and higher elevations are subject to colder temperatures, including frost during the growing season, which can adversely affect seedling survival.

Adding HABTYP to the model substantially increased the significance of the coefficients for both ELEV and ELEV2, and slightly raised the corrected R-squared value. The bootstrap analysis indicated the positive coefficient of HABTYP would probably have been smaller if autocorrelation had not existed in the model.[59] The strong correlation of HABTYP with elevation indicated that multicollinearity existed in the model, for which no corrections were made.

According to Pfister et al. (1983), timber productivity is

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[58]The importance of the timing of burns with respect to both fire intensity and seed dispersal is emphasized in DeByle (1981) and Lotan and Perry (1983). In a study of the effects of burning on clearcuts in northwest Montana, Shearer (1984) found significantly higher stocking of natural regeneration and better seedling vigor on burned units than on unburned units; the burns had occurred four years prior to a bumper seed crop in 1971.

[59]Using the bootstrap coefficient for HABTYP, the model would predict 15 less effective TPA for ABLA habitat types, *ceteris paribus*.

generally higher on lower elevation subalpine fir (ABLA) sites (5800 to 6400 feet in this data set) than on Douglas-fir (PSME) sites (4300 to 5600 feet in this data set), so it is not unreasonable to find that the data indicate more successful regeneration on the ABLA sites. There was one case from the ABGR (grand fir) series in the data set, which had an elevation of 5300 feet; it was included with the ABLA series because it represents more mesic conditions, similar to the ABLA sites.

Figure 6 illustrates the effects of elevation and habitat type, holding the values of other variables in the model constant.

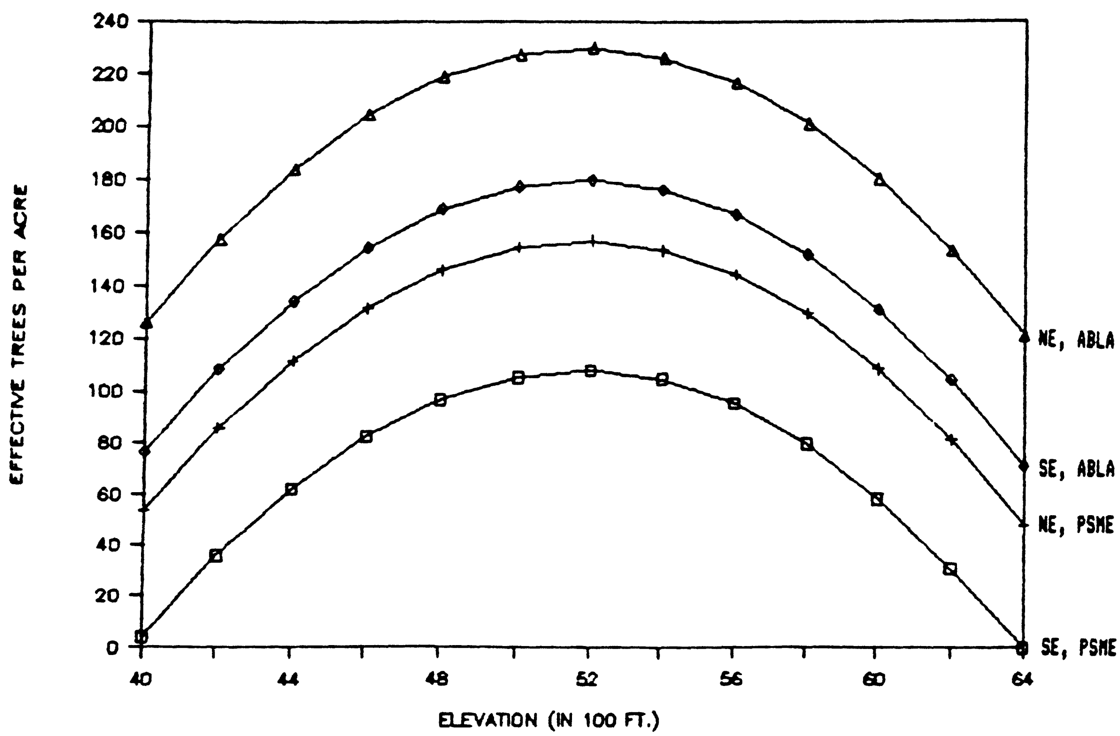

Figure 6 ETPA_NAT by Elevation, Habitat Type and Aspect (unburned stands, 36% slope, 5 years since disturbance, 1 year between harvest and disturbance)

ACRES was not included in NATMOD because its coefficient was not significant at the .05 level, but since it is important for planning and scheduling harvest treatments, it warrants a brief discussion. In the preliminary models which included ACRES, it showed a negative effect on ETPA_NAT, which would be expected because as stand size increases, there is more area farther from potential seed sources, as well as decreasing protection from radiant heat and desiccation due to wind. Especially where ponderosa pine regeneration is desired, smaller-sized units are preferable because of the heavier seed of that species. ACRES did not appear to interact with other variables in the model, and its effect was minor; for every additional 10 acres in stand size, there was a decrease of approximately 5 effective trees per acre. The range of ACRES in the data set was 2 to 50, with a mean of 12.5.

Three other variables not included in NATMOD also deserve some attention: RESIDS, the number of residual trees over five inches in diameter per acre, SCAR, whether or not a stand was scarified after harvest, and NONE, representing the effects of no site preparation. One might expect these variables to exert some influence on stocking levels of natural regeneration, so the low significance of their coefficients when added to NATMOD is interesting.

The presence of residual trees (represented by either RESIDS or LNRESID, the natural logarithm of the number of residuals per acre) showed no significant effect on ETPA_NAT at the .05 level in any of the preliminary models. The coefficients were positive when either variable was entered into the equation, as expected, since the negative effect of occupying growing space would likely be compensated for by shade, protection from wind, and any seed provided by a residual tree.

The coefficient of LNRESID was slightly more significant than that of RESIDS, and the two variables together created a positive logarithmic curve, indicating that as the number of residuals on a stand increased past a certain point, the observed ETPA_NAT levelled out asymptotically. Although this result was not statistically significant at the .05 level, it does reflect the purpose and intent of regeneration harvests.

SCAR was positive and significant at the .05 level by itself and with NONE, but negative and insignificant with BURN. The *F*-value and *R*-squared were both lower with SCAR in the model. Like BURN, SCAR was a dichotomous variable with no indication of the treatment's severity; estimates of the percent of exposed mineral soil or vegetative competition as a result of the treatment were not available.

The dichotomous variable NONE (1 if no site preparation and 0 if site preparation occurred after harvest) was positive and significant at the .05 level by itself and with SCAR, but negative and not significant with BURN. It is not surprising that the effects of NONE and SCAR overlap; often during a harvest, adequate scarification occurs while logs are being skidded to the landing, making additional site preparation treatments unnecessary, especially on dry sites where vegetative competition and duff depth are lower.

It should be reiterated that this model was not intended to quantify the effects of different treatments, although it does indicate which variables were most significant for this data set. In order to more precisely determine the effects of site preparation, it would be necessary to compare the results from different treatments on similar sites during the same time period by conducting an analysis of variance.

<u>Effects of Time, Aspect, and Slope in NATMOD</u>

The remainder of the discussion of NATMOD focuses on the variables which represent the effects of time, aspect and slope on ETPA_NAT: DIST_TO_EXAM2, HARV_TO_DIST, and THREE_VARS. With no other variables in the model besides the intercept, DIST_TO_EXAM2 was the first to come into the equation on the basis of its significance and contribution to the model's predictive ability, with a *t*-stat of 4.81 and a corrected *R*-squared of .22 for the initial model.

In plotting the values of the equation for the final version of the model, with ETPA_NAT on the y-axis, years since disturbance on the x-axis and other variables held constant, the effects of time in both DIST_TO_EXAM2 and THREE_VARS interacted to create a positive exponential curve of stocking over time. That the squared term of DIST_TO_EXAM resulted in a better fit than DIST_TO_EXAM itself is interesting since it indicates the <u>rate</u> of stocking increased over the period of time represented by the data (2 to 8 years). Over a longer period of time, it is likely that the curve would become sigmoidal, i.e., at some point the rate of increase would slow down and eventually the increase itself would level off.

Time between harvest and disturbance (HARV_TO_DIST) had a significant and positive coefficient, and its contribution to the F-value of the model equation is likely due in part to its interaction with DIST_TO_EXAM2. HARV_TO_DIST alone might be expected to be negatively correlated with stocking levels. However, in this model, it modifies the relationship between time since disturbance and stocking by predicting higher stocking levels in the early years between disturbance and exam than if DIST_TO_EXAM2 were in the model by itself.

For example, there were four cases which had a HARV_TO_DIST value of 5 years, but in spite of a low DIST_TO_EXAM value of 2 years, their observed ETPA_NAT values were moderately high, and much higher than other cases with a DIST_TO_EXAM value of 2 years. It appears that the scarification which occurred at year 5 on those stands did not appreciably disturb either the seedlings which had started growing after the harvest or the advance regeneration. Thus, the meaning of years between harvest and disturbance in this model lies partially in the additive function HARV_TO_DIST + DIST_TO_EXAM = HARV_TO_EXAM.

HARV_TO_DIST was positively correlated with scarification, but not correlated with burning. When BURN was taken out of the model, the t-stat of HARV_TO_DIST (1.45) became insignificant at the .05 level, the R-squared dropped to .387, and the F-ratio was 9.31. HARV_TO_DIST was not significant at the .05 level when SCAR was included instead of BURN, but SCAR was positive and significant at the .01 level (the corrected R-squared and F-ratio for that model were low).

THREE_VARS represents the concept that rates of stocking over time vary for different aspects and slopes by incorporating the effects of COSASP, SQRTSLOPE, and DIST_TO_EXAM. Its relatively small coefficient (1.1745) indicates there was not much difference between the rates, and its t-statistic of 2.726 means it was significant at the .01 level. COSASP has a positive effect within the term because, on the average, northerly aspects have higher values for ETPA_NAT; since temperatures are lower and soil moisture is higher on northerly aspects due to reduced solar radiation, major influences on seedling growth and survival are realistically reflected in this variable. Figure 7 shows the effects of time on predicted ETPA_NAT by habitat type and aspect.

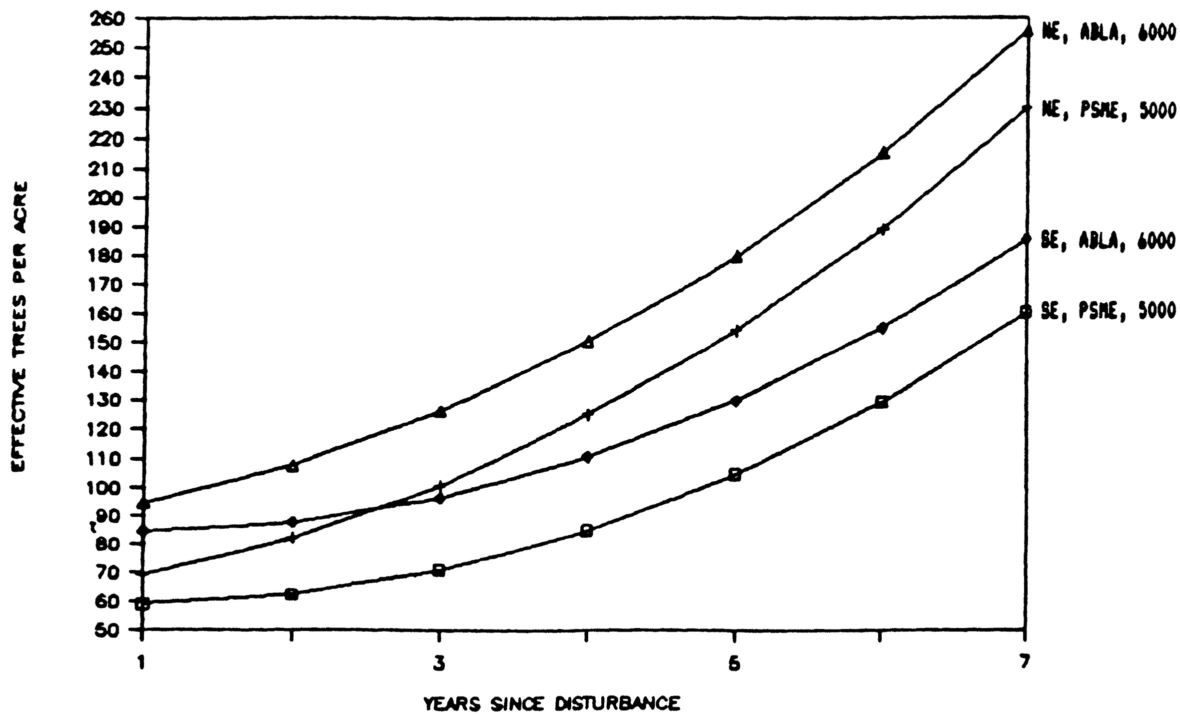

Fig. 7 ETPA_NAT by Time Since Disturbance, Habitat Type and Aspect (unburned stands, 36% slope, average elevation for each habitat type group)

Slope steepness (represented by SQRTSLOPE in THREE_VARS) accentuates the effects of aspect, i.e., the positive effects of north aspects and negative effects of south aspects; this result agrees with findings by Ferguson et al. (1986). Figure 8 shows the combined effects of time, slope and habitat type on predicted ETPA_NAT.

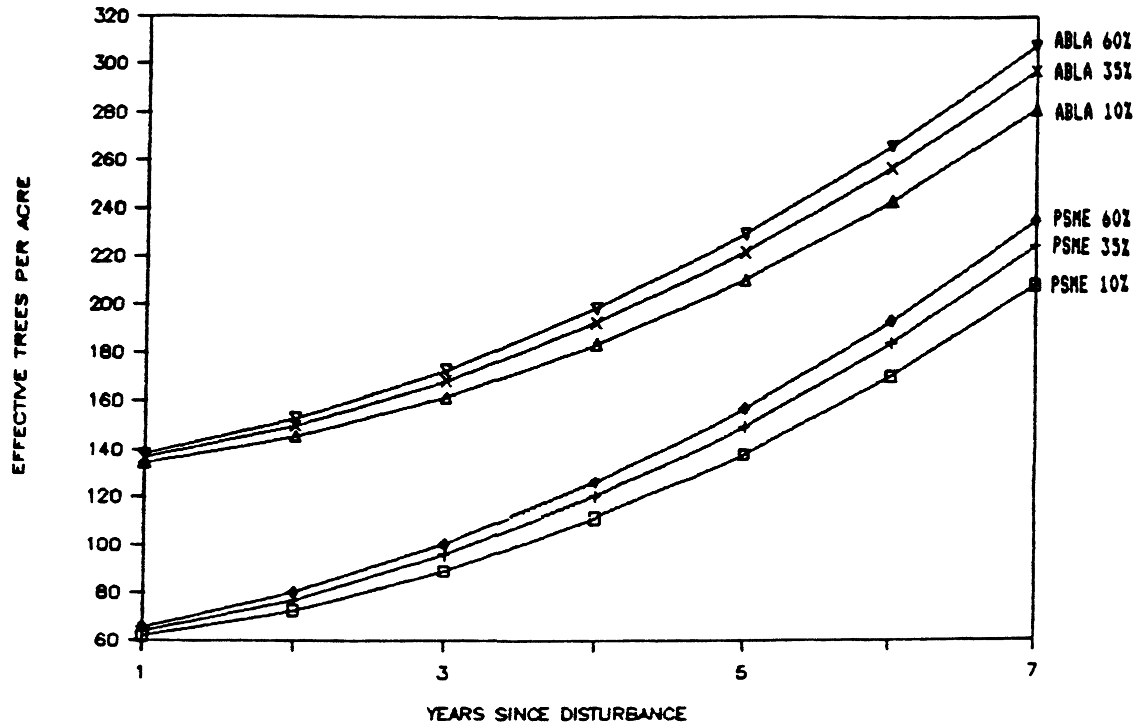

Figure 8 ETPA_NAT by Time Since Disturbance, Habitat Type and Slope (unburned stands, NE aspect, 5500 feet elevation)

Since north slopes receive even less solar radiation as they become steeper, they provide cooler and moister conditions which are beneficial for seedling survival, especially at lower elevations where there is less precipitation (after regeneration establishment on steeper slopes, tree growth rates would likely become adversely affected since soil depth and fertility tend to decrease with increasing slope). Figure 9 (next page) shows the effects of time on predicted ETPA_NAT by habitat type slope and aspect, and Figure 10 shows the effects of time, aspect and slope.

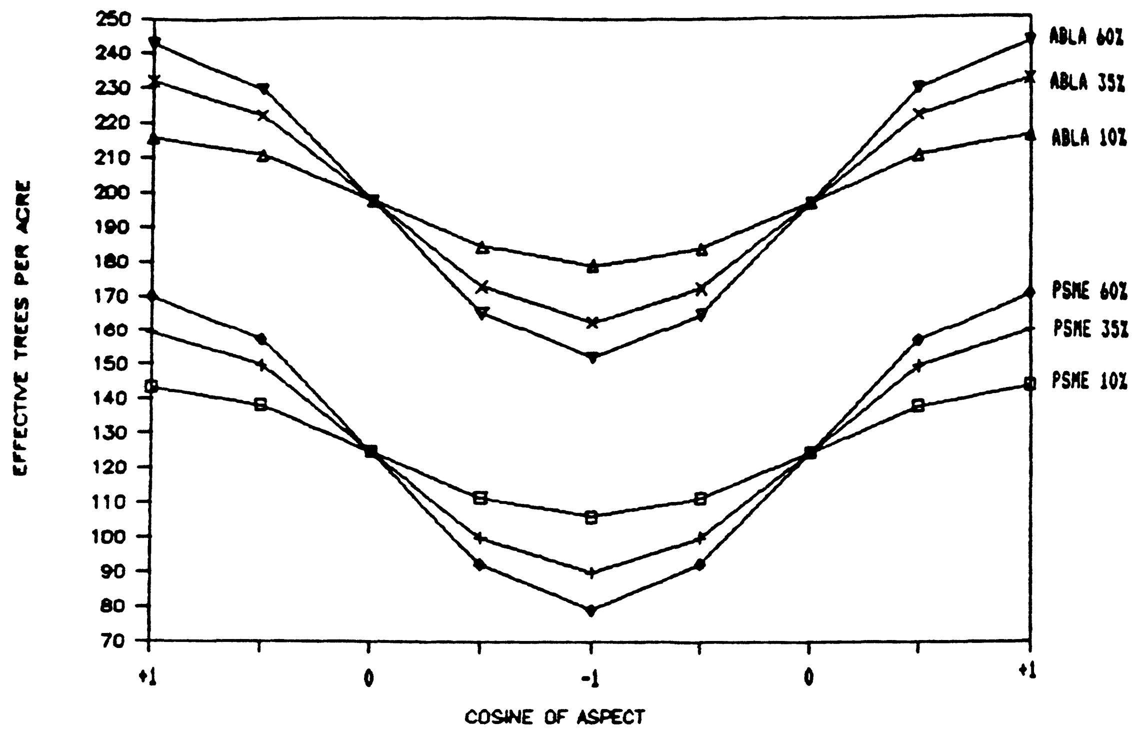

Figure 9 ETPA_NAT by Aspect, Slope and Habitat Type (unburned stands, 5500 feet elevation, 5 years since disturbance)

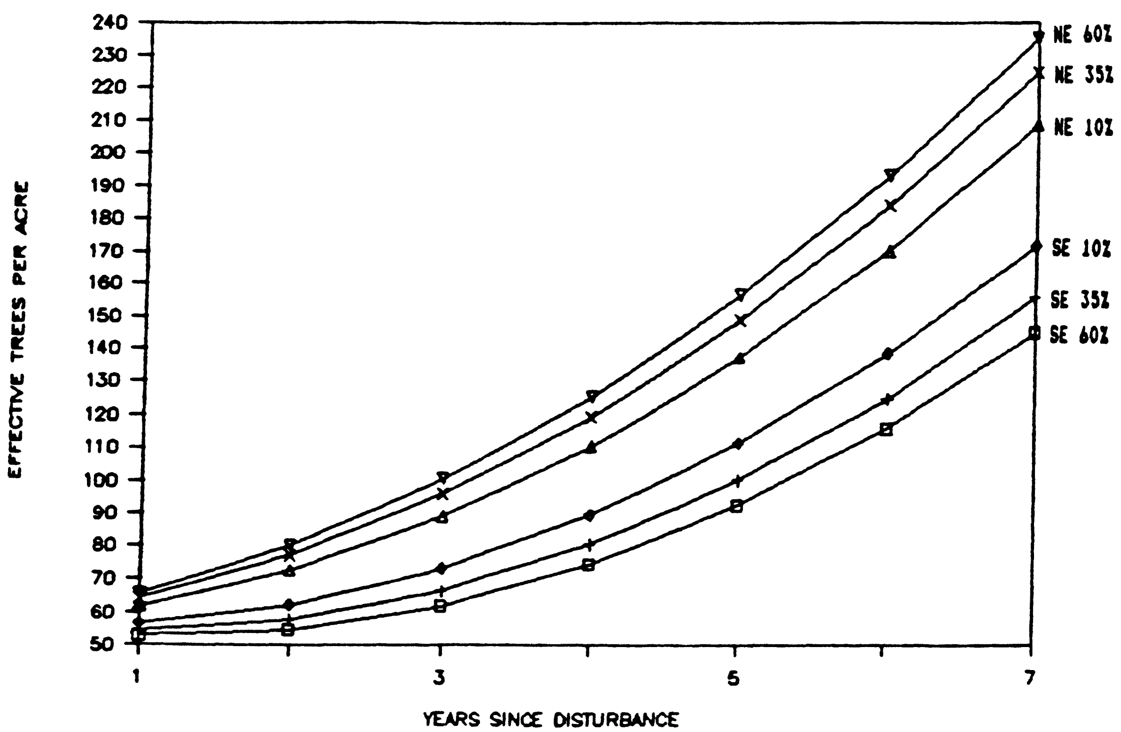

Figure 10 ETPA_NAT by Time Since Disturbance, Aspect and Slope (unburned stands, PSME habitat types, 5500 feet elevation)

Chapter 8

Summary and Interpretation of the Regression Model for Effective Stocking of Natural and Planted Regeneration (NAPLMOD)

Summary of NAPLMOD

NAPLMOD is the linear regression model for ETPA_NAPL, the dependent variable for effective stocking (ETPA) of combined natural and planted regeneration. Eighty cases were derived from systematic plot exams on stands harvested from 1980 to 1982 on the Missoula District (see Chapter 4 for a discussion of the sample and variables, and Chapter 5 for a summary of the data set). Table 10 summarizes the model.

Table 10

Summary of NAPLMOD

Variable	Meaning	Mean	Coeff.	T-stat
ETPA_NAPL	dependent variable	172.3	---	---
INTERCPT	intercept of equation	---	33.259	2.011[2]
HABTYP	= 1 if ABLA or ABGR series, 0 if not	.33	60.822	4.137[1]
DIST_TO_EXAM2	squared term of time between exam and last disturbance	16.8	3.8201	4.630[1]
THREE_VARS	a multiplicative term: COSASP (cosine of stand aspect) * SQRTSLOPE (square root of SLOPE) * DIST_TO_EXAM (years between disturbance and exam)	6.8	1.0596	2.398[1]
PLANTD	= 1 if stand was planted, 0 if not	.54	241.78	6.661[1]
PLNT_TO_EXAM	years between planting and exam	1.03	-42.666	-4.061[1]
DIST_TO_PLNT	years between disturbance and planting	1.04	-36.773	-3.853[1]

F-ratio:	19.34	Significance of coefficients
R-squared:	.614	[1] significant at .01 level
Corrected R-squared:	.582	[2] significant at .05 level

The strong *F*-ratio and moderately high *R*-squared value suggest this is a reasonable model given the available survey data. All of the coefficients except that of INTERCPT are significant at the .01 level. As with NATMOD, a bootstrap analysis was performed to test the stability of the coefficient variances (described in more detail in Chapter 7 and Appendix J). The analysis indicated that the NAPLMOD coefficients would not have changed appreciably in the absence of autocorrelation.

Effects of Independent Variables in NAPLMOD

The main focus of this discussion will be on the variables included in the final version of NAPLMOD, especially those related to planting. There are three variables which appear in both NATMOD and NAPLMOD: HABTYP, DIST_TO_EXAM2, and THREE_VARS (the multiplicative term of cosine of aspect, square root of slope, and time between disturbance and exam). The coefficients of those three variables are positive and of the same magnitude in NAPLMOD as they were in NATMOD, indicating that beyond their significance in the data sets, they represent important factors in the regeneration process. Since the meanings of HABTYP, DIST_TO_EXAM2, and THREE_VARS are similar in both models, the discussion of their effects will not be repeated here (refer to Chapter 7).

Figures 11, 12 and 13 (below) illustrate some of the combined effects of these three variables on predicted ETPA_NAPL, with the values for the other independent variables held constant. The underlying assumptions are that planting occurs at one year after disturbance, and the first exam occurs at year one after planting, so the origin of the x-axis is at 2 years between disturbance and exam.

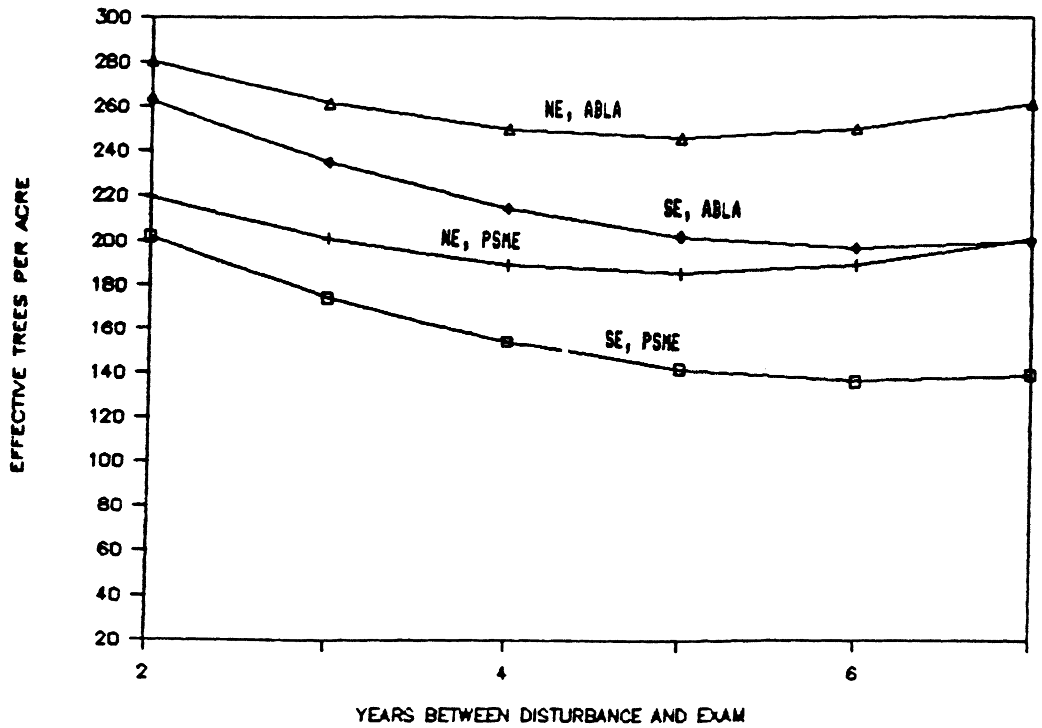

Figure 11 ETPA_NAPL by Years Since Disturbance, Habitat Type and Aspect (on planted stands, 35% slope, 1 year between disturbance and planting)

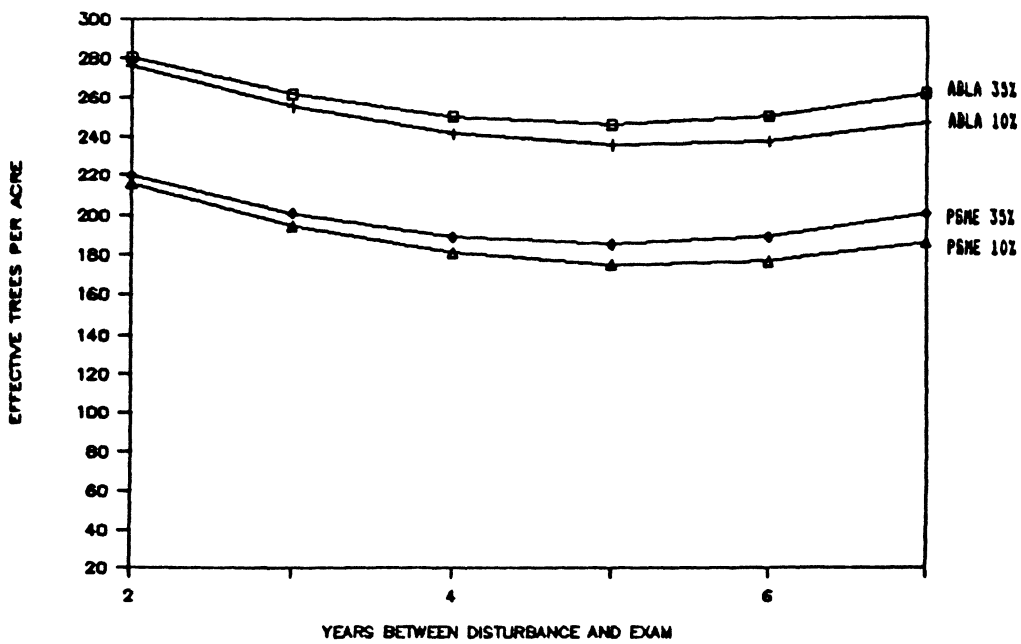

Figure 12 ETPA_NAPL by Years Since Disturbance, Habitat Type and Slope (on planted stands, NE aspect, 1 year between disturbance and planting)

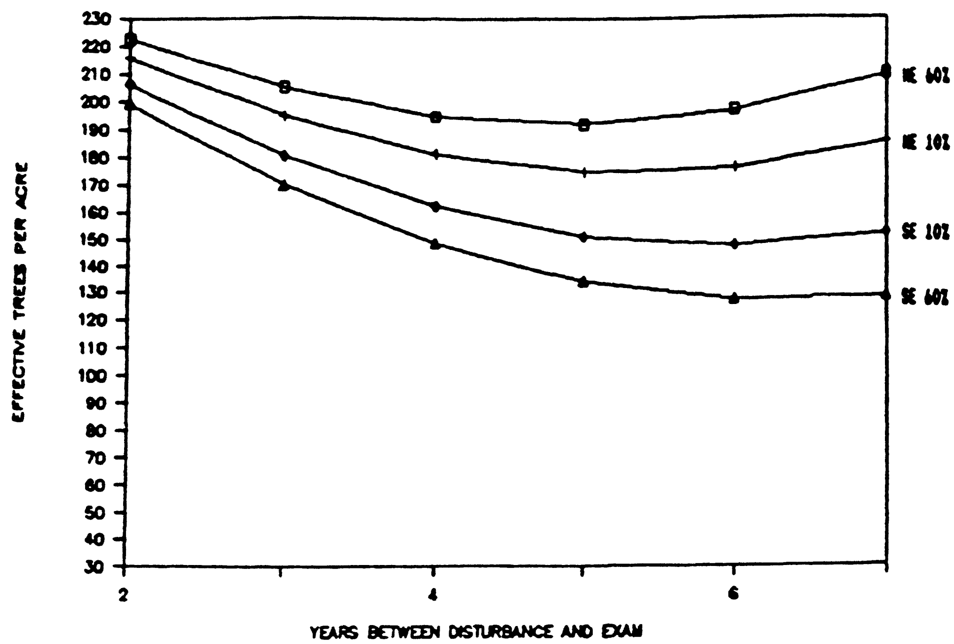

Figure 13 ETPA_NAPL by Years Since Disturbance, Slope and Aspect (on planted stands, PSME habitat types, 1 year between disturbance and planting)

The absence of ELEV in NAPLMOD is interesting because the other models, NATMOD and the LOGIT models for certifiability (discussed further in Chapter 9), showed very strong effects due to elevation. In NATMOD, where only stocking of natural regeneration was considered, the effect of elevation was quadratic due to both ELEV and its squared term being in the equation; peaking at 5200 feet, it indicated that natural regeneration stocking levels were higher in the middle elevations.

In NAPLMOD, where the dependable variable included both planted and natural seedlings, the decision to plant (represented by PLANTD) was highly significant and apparently counteracted the function of elevation in predicting effective trees per acre (the coefficients for ELEV and ELEV2 were not significant at the .05 level). Proportionately more stands were planted in the upper elevations than in the middle or lower elevations; because they were planted, higher elevation stands tended to have higher ETPA_NAPL values.

PLANTD, the dichotomous variable of whether a stand had been planted or not, was positive and very significant, as expected;[60] the large coefficient was likely due in part to good initial survival on most of the plantations (the average number of trees planted per acre was 340). Surveys taken immediately after planting were almost always plot exams, and unless the plantation failed right away, those surveys showed, on the average, a higher ETPA_NAPL than the unplanted stands.[61]

An unestimated bias was introduced since both NAPLMOD and NATMOD reflect only data from plot surveys. Proportionately more walk-through exams than plot surveys were taken on certifiable stands, and there were insufficient plot survey data to determine whether effective trees per acre would actually be higher over time than either model indicates.

The negative coefficient of DIST_TO_PLNT indicates that the more time which elapsed between site preparation and planting, the lower the effective stocking. The negative coefficient for PLNT_TO_EXAM (years between planting and the exam) indicates that stocking on plantations did not increase over time, and initially decreased somewhat, presumably due to mortality of planted seedlings and slow regeneration of natural seedlings. In Figures 14 and 15, the regeneration on unplanted stands

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[60]When the value of PLANTD is 1, with other variables held constant, the model predicts an additional 242 effective trees per acre.

[61]Of the 80 cases, 43 were from surveys on planted stands; 30 of those cases had ETPA_NAPL values of more than 200, and only 5 of the 43 exams on plantations had an ETPA_NAPL of less than 100 (only 7 of the 37 exams on unplanted stands had an ETPA_NAPL of more than 200, and 18 of those 37 exams had ETPA_NAPL values of less than 100).

exceeded that on planted stands around year 6 after disturbance. This is partly a result of assigning unplanted stands with values of 0 for

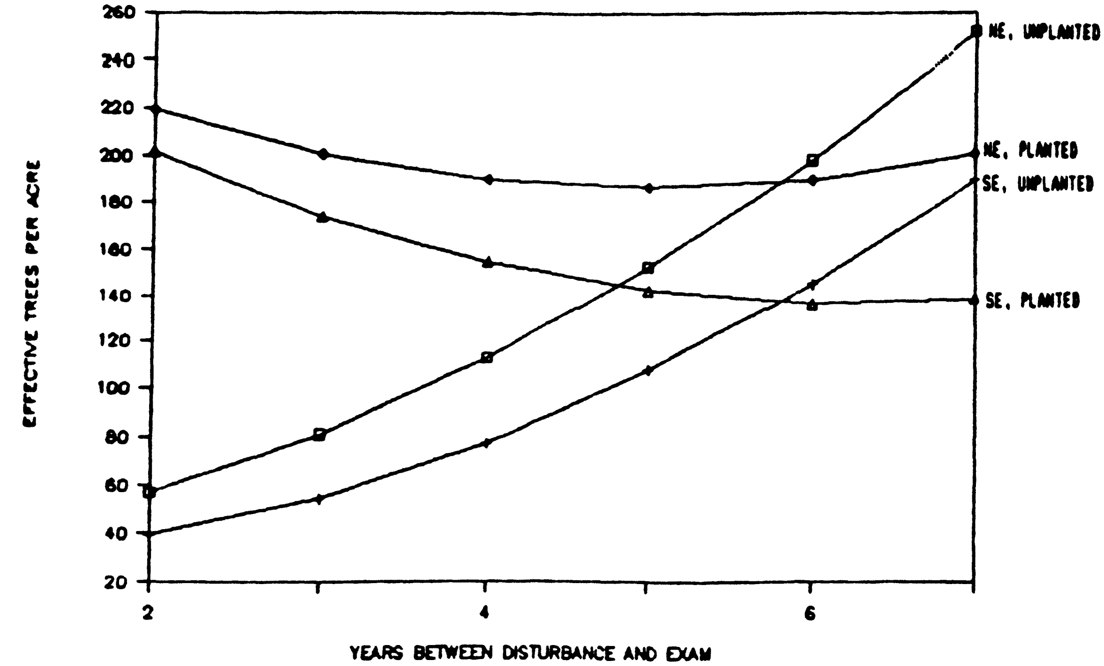

Figure 14 Predicted ETPA_NAPL by Time and Aspect on PSME Habitat Types (planted stands with DIST_TO_PLNT = 1, 35% slope)

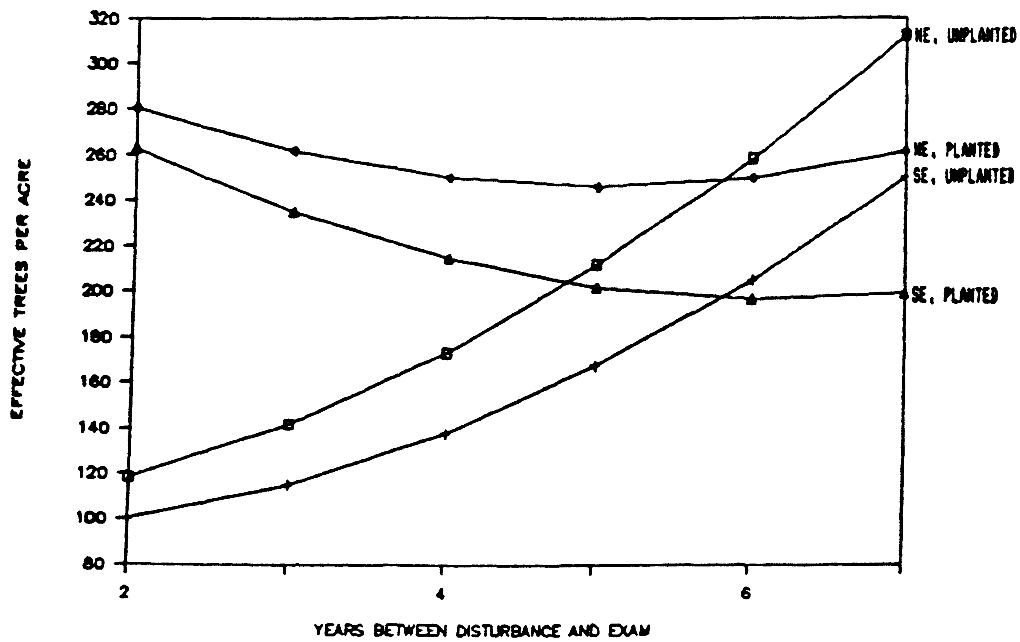

Figure 15 Predicted ETPA_NAPL by Time and Aspect on ABLA Habitat Types (planted stands with DIST_TO_PLNT = 1, 35% slope)

DIST_TO_PLNT and PLNT_TO_EXAM, and also reflects the management decision not to plant when good natural regeneration is anticipated.

None of the three variables related to site preparation contributed enough to the model to be included. Unlike NATMOD, BURN was not significant with any combination of variables. When SCAR was added to the equation, it had a positive *t*-value, significant at the .05 level. This did not affect the DIST_TO_PLNT coefficient very much (SCAR and DIST_TO_PLNT were apparently not highly correlated) and raised the *R*-squared slightly; however, because it reduced the *F*-value to 17.75 and made the INTERCPT coefficient insignificant at the .05 level, it was left out of NAPLMOD. Adding NONE reduced the corrected *R*-squared to .515, and the *F*-value to 14.99 (the *t*-stat for NONE was -1.645).

Two variables related to planting, PLUGS and CREW, were not included in the model, but are briefly discussed here because they might be of interest to managers. The dichotomous variable, PLUGS had a value of 1 if container stock was planted and 0 if not (bare root stock and unplanted); PLUGS had a coefficient not significantly different from 0 at the .05 level.

So far there is little evidence that container stock results in better plantation survival than bare root stock. Both types have advantages and disadvantages; the main advantage of container stock is that it allows for flexibility in scheduling planting (bare root stock must be ordered 3 years ahead and, in the study area, can only be planted in the spring).[62]

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[62]Reforestation Handbook, Sec.323, 8/85 Amend 28 (U.S.D.A. Forest Service, 1985).

CREW, the dichotomous variable with a value of 1 if the planting was done by a contracted crew and 0 if not (Forest Service crew or unplanted), was negative and significant at the .10 level, but not at the .05 level. Although the negative coefficient indicated that contracted plantations had a lower ETPA_NAPL, as it turned out, many of the stands planted by Forest Service crews were interplants on stands which had fairly good natural regeneration except for scattered openings. On the other hand, many of the stands planted by contractors were clearcuts on difficult terrain, as indicated by comments on the survey forms. Thus, CREW was not useful as an explanatory variable for this data.[63]

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[63] My personal experience leads me to believe that the health and vigor of planting stock at the time of planting is more critical than the type of planting stock (container vs. bareroot). Likewise, the physical condition and motivation of the planting crew and more important than whether the crew is contracted or comprised of Forest Service employees; a treeplanting crew must be inspired to plant trees according to specifications, reinforced by strict and effective quality control.

Chapter 9

Summary and Interpretation of LOGIT Models for Probability of Certifiability

Chapters 7 and 8 described the two linear regression models for effective stocking. This chapter discusses two LOGIT probability models, called DIST5CERT and HARV7CERT, which were developed to estimate the probability of a stand being certifiable as stocked.[64]

In the LOGIT models, the dichotomous dependent variable of certifiability was determined on the basis of whether natural and planted regeneration met the prescribed stocking level for a stand within two different time frames, taking the value of 1 if certifiable and 0 if not. Trees-per-acre and stocking percent estimates from both plot and walk-through surveys were used to determine certifiablity, instead of the ETPA derived from Stage (1974), which was calculated from plot data only. In DIST5CERT, 38% of the surveys were walk-throughs and in HARV7CERT, 31% were walk-throughs.

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[64]The LOGIT models are based on the cumulative logistic probability function, using the Maximum Likelihood technique to estimate the parameters. The form of the LOGIT equation is:

$$P_i = \frac{1}{1 + e^{-(\alpha + BXi)}},$$

where the dependent variable is the probability that a particular choice will result, given the conditions represented by the independent variables (in this study, the measured dependent variable is the "choice" of whether or not a stand is certifiable). Due to the sigmoidal logistic curve, changes in independent variables have their greatest impact on the probability of a given result at the midpoint of the distribution, and the least impact at the endpoints. There are excellent discussions and examples of LOGIT models in Kmenta (1986) and Pindyck and Rubinfeld (1981).

During the initial stages of the modelling process, I included the several variables related to time as independent variables; this resulted in LOGIT models which estimated the probability of a stand being certified at any particular year after disturbance or harvest, rather than by a certain year. In the final models, time was instead incorporated into the dichotomous dependent variables: CERT_5YR (in DIST5CERT) represents certifiability by five years after disturbance and CERT_7YR (in HARV7CERT) represents certifiability by seven years after harvest.[65]

Not all of the 54 study stands had exams taken at or near the end of those two periods; thus, in order to fit the time frames, two new data sets were created from the original data. For example, if the most recent exam for a stand was three years since the site preparation, it was not included in the data set for DIST5CERT; if the same exam was taken seven years after the harvest, the stand was included in the HARV7CERT analysis. DIST5CERT had 39 stands out of the original 54 stands, and HARV7CERT had 45 stands.[66]

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[65]The time frames were chosen to approximate the NFMA regeneration time limit of five years after harvest, and to accommodate the modelling process. With this data, only 5% of the stands were certifiable by five years after harvest; by six years, 13% of the stands were certifiable, and by seven years after harvest, 44% of the stands were certifiable. LOGIT yields more reliable results when the proportion is near 50%, thus I chose the 7-year time frame for HARV7CERT. The five-year time frame for DIST5CERT is related to that for HARV7CERT, since the average time between harvest and disturbance was approximately 2 years.

[66]Six of the stands not included in the models were part of land exchanges and were no longer being monitored by the Forest Service. The other stands not included either had not been examined in 1988, did not have available survey records, or not enough time had passed since their site preparation.

Summary of DISTSCERT

Table 11 shows the coefficients and statistics for the final version of DIST5CERT. Although the coefficients and t-stats of the LOGIT model have the same meaning as in a linear regression model, the statistics which describe the model as a whole are different. The "percent correctly predicted" statistic compares the actual values of the dichotomous dependent variable with those predicted from the equation. The Likelihood Ratio Index (LRI)[67] is analogous to the *R*-squared statistic in that it represents the amount of variation explained by the model. Instead of the *F*-ratio, the analogous test for

Table 11

Summary of DIST5CERT

Variable	Meaning	Mean	Coeff.	T-stat
INTERCPT	intercept of equation	----	173.6	2.509[1]
HABTYP	= 1 if ABLA or ABGR habitat series, 0 if not	.436	2.436	1.456[3]
ELEV	elevation, in 100 ft.	54.9	-6.256	-2.517[1]
ELV2	the squared term of ELEV	3050.5	.05572	2.505[1]
ACRES	stand size, in acres	13.2	-.1003	-2.010[2]

Percent correctly predicted:	84.6
Likelihood Ratio Index:	.351
Chi-squared:	18.3

Significance of coefficients
[1] significant at .01 level
[2] significant at .05 level
[3] significant at .10 level

[67]The Likelihood Ratio Index (LRI) is defined as:

$$LRI = 1 - \frac{L(max)}{L(0)},$$

where L(max) is the maximum value of the log-likelihood function and L(0) is the maximum value of this function under the constraint that all parameters are set equal to zero (Kmenta, 1986).

model significance uses the Chi-squared statistic.[68] The relatively high "percent correctly predicted" and Chi-squared indicate that DIST5CERT reasonably reflects the data, but it is not recommended for prediction purposes because of the high unexplained variation (low LRI).

The evaluation of the LOGIT model is more complex than for a linear regression model. After setting the values for the independent variables and finding the total value of the right-hand side (RHS) of the LOGIT equation given in Footnote 64 above, one then takes the antilogs of both sides. With some algebraic manipulation, the result is $P_i = e^{RHS}/(1+e^{RHS})$. P_i is the probability of the dependent variable having a value of 1 for given values of the independent variables; in Figures 16 and 17, P_i is on the Y-axis, and represents the probability of a stand being certifiable by five years after disturbance.

Effects of the Independent Variables

What is immediately noticable about DIST5CERT are the effects on CERT_5YR (the dependent variable for certifiability) from the variables ELEV and ELEV2. The quadratic curves in Figures 16 and 17 reflect the data since 50% of the stands at lower elevations (below 5000 feet) and 75% of the stands above 6000 feet were certifiable five years after disturbance; only 16% of the stands with elevations between 5000 and

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[68]The Chi-square statistic is used to test the null hypothesis that the independent variables are irrelevant in determining the expected value of the dependent variable. Its expression is -2[L(0) - L(max)], where L(0) is the maximum value of the log-likelihood function under the constraint that all parameters besides the constant are set equal to zero and L(max) is the maximum value of the log-likelihood function. The statistic follows a Chi-square distribution with k degrees of freedom, where k is the number of explanatory variables (Kmenta, 1986).

6000 feet were certifiable. In Figures 16 and 17, the elevational limits are appropriate for each habitat type series with this data set.

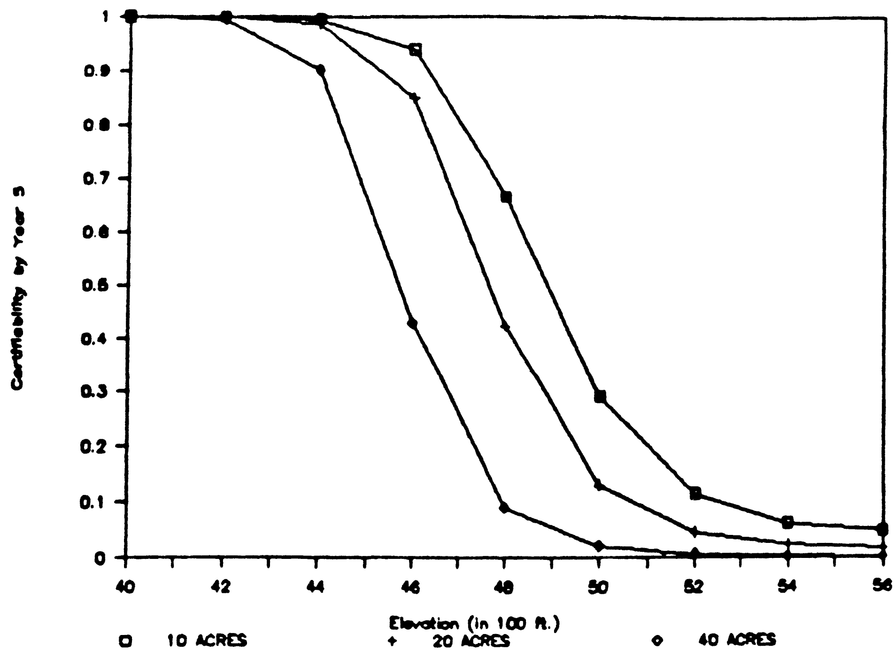

Figure 16 Certifiability 5 Years after Disturbance on PSME Habitat Types (by elevation and acres)

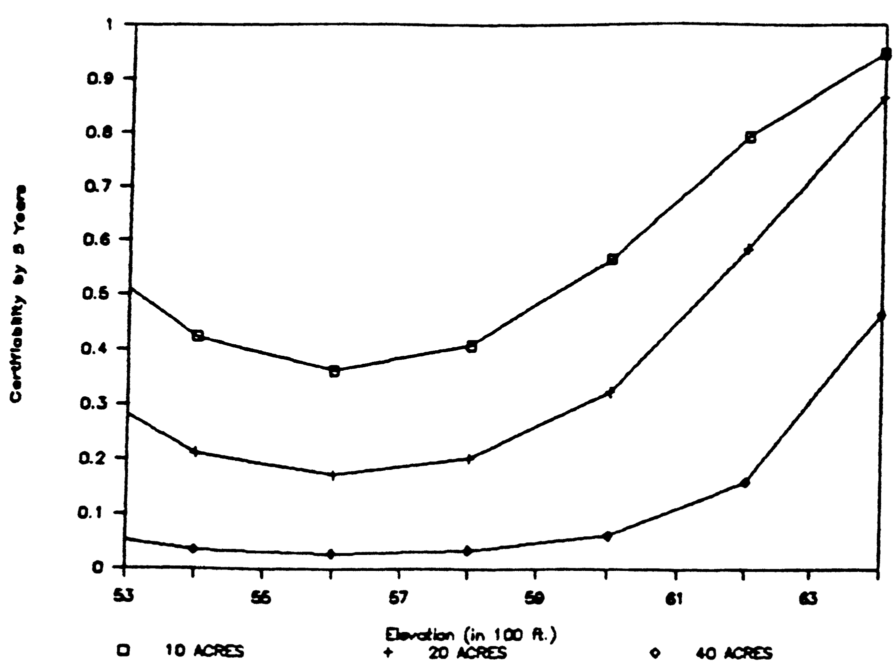

Figure 17 Certifiability 5 Years after Disturbance on ABLA Habitat Types (by elevation and acres)

The effect of elevation initially appears to be an odd result since the general form of the elevation curves for DIST5CERT is completely opposite that of the curves which graph the effects of elevation in NATMOD (see Figure 6). After a closer look, there are two plausible explanations, one of which has to do with multicollinearity (correlation between independent variables) and the other with the nature of the data and dependent variables in the two models.

First, the elevation variables were multicollinear with PLANTD in DIST5CERT (PLANTD was significant at the .05 level without ELEV and ELEV2, but contributed less than the elevation variables to the overall explanatory value of the model). The multicollinearity existed because in the data set used for DIST5CERT, there were proportionately more planted stands in the upper elevations (above 6000 feet) than in the lower and middle elevations, and more unplanted stands in the middle elevations. Of the planted stands in the upper elevations, 71% were certifiable;[69] the one lower elevation planted stand was certifiable, and none of the 6 middle elevation planted stands were certifiable by year 5 after the disturbance.[70] Thus, the effect of elevation substituted to some extent for the effect of planting decisions.

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[69]In spite of having higher prescribed stocking levels of 300 trees per acre (vs. 200 trees per acre on most of the stands), the upper elevation stands apparently met the higher trees-per-acre certifiability standard due to successful plantations.

[70] The four lower elevation stands which were certifiable in DIST5CERT had some unusual characteristics: one stand was planted and had a habitat of ABLA/VACA, often found at higher elevations or in frost pockets. Two of the three certifiable lower elevation stands which were not planted had prescriptions for 150 trees per acre (certifiable at a lower limit), and the third was a 2-acre seed tree unit.

In addition to multicollinearity, there were some basic differences between DIST5CERT and NATMOD which help to explain the opposite effect of elevation in the two models. Most significantly, NATMOD included effective trees per acre of natural regeneration only, whereas DIST5CERT included both planted and natural regeneration. Also, unlike NATMOD, the data set for DIST5CERT included results from walk-through surveys, some of which were certification surveys; conversely, the time frame for DIST5CERT did not include exams taken on stands later than five years after disturbance, whereas the data set for NATMOD included all available plot exams.

Aside from the fact that the two models are not directly comparable, the interpretation of their results is not contradictory. In NATMOD, natural regeneration occured sooner on middle elevation stands (this is likely the reason most of those stands were not planted); given the results from DIST5CERT, it appears that planting increased the stocking on higher elevations enough for those stands to certifiable at five years after disturbance, but that unplanted stands, even those at the middle elevations with relatively good natural regeneration, were not certifiable within that time frame.

ACRES was significant at the .05 level and its negative coefficient indicated that as stand size increased, the probability of certifiability decreased. This is an expected result, since a smaller unit is likely to have more seeding from the adjacent overstory.

HABTYPE was included in the model even though it was significant only at the .10 level because of its interest to managers (it was more significant than any of the other variables which were not included).

Stand size (ACRES) had a more pronounced effect on stands with wet habitat types due to the logistic function; one possible meaning of that result is that regeneration was limited less by moisture than by seed availability on those stands.

The other variables related to planting, CREW, PLUGS, PLNT_TO_EXAM and DIST_TO_PLNT were not significant at the .05 level. Slope and aspect were not good explanatory values in this model, but are represented in the other LOGIT model of certifiability (HARV7CERT).

Summary of HARV7CERT

Table 12 summarizes HARV7CERT, the LOGIT probability model with 45 cases from plot survey and walk-through exams at or near 7 years after harvest; of the 45 cases, twenty were certifiable and 25 were not.

Table 12

Summary of HARV7CERT

Variable	Meaning	Mean	Coeff.	T-stat
INTRCEPT	intercept of equation	---	265.7	2.319[1]
ELEV	elevation, in 100 ft.	55.5	-9.634	-2.323[1]
ELV2	the squared term of ELEV	3113.8	.08587	2.317[1]
SLOPE*COSASP	stand slope * cosine of aspect	32.5 *.451	.09539	2.166[2]
DIST_TO_PLNT	years between disturbance and planting	1.4	-2.492	-2.327[1]
PLNT_TO_EXAM	years between planting and exam	1.4	3.549	2.394[1]

		Significance of coefficients
Percent correctly predicted:	84.4	[1] significant at .01 level
Likelihood Ratio Index:	.590	[2] significant at .05 level
Chi-squared:	36.5	

This is a stronger model than DIST5CERT in terms of the Likelihood Ratio Index (LRI) and the Chi-squared statistic, and has an equivalent value for "percent correctly predicted." All of the variables, except for SLOPE*COSASP, are significant at the .01 level.[71]

The coefficients for elevation (ELEV) and its squared term, ELV2, had an even stronger influence in HARV7CERT than in DIST5CERT, but their significance in the model was slightly less. As in DIST5CERT, most of the uncertifiable stands at the middle elevations had not been planted; thus, there was some multicollinearity between elevation and planting.

Figure 18 (next page) shows the effects on CERT_7YR (the dependent variable of probability of being certifiable seven years after harvest) of elevation by aspect and planting, with a constant slope. The model indicates that stands with NE aspects had a higher probability of certifiability by year 7 after harvest than on the SE aspects, especially if they were planted.[72]

Figure 19 shows the effects on CERT_7YR of elevation, slope and aspect (on planted stands, with time related to planting being constant). The trend due to elevational effects is similar to that in Figure 18, and the slope-aspect interaction is in accordance with other findings (Ferguson, et al., 1986, and Dolezal, 1982).

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[71]Habitat type (HABTYP) had a positive coefficient but was not significant at the .10 level when included in preliminary versions of the model. Although HABTYP was not included in the final model, its effects were likely incorporated into those of elevation and aspect.

[72]In Figure 18, planted stands have a value of 2 for DIST_TO_PLNT and 3 for PLNT_TO_EXAM; stands which were not planted have a value of 0 for both variables, since that condition existed only for unplanted stands.

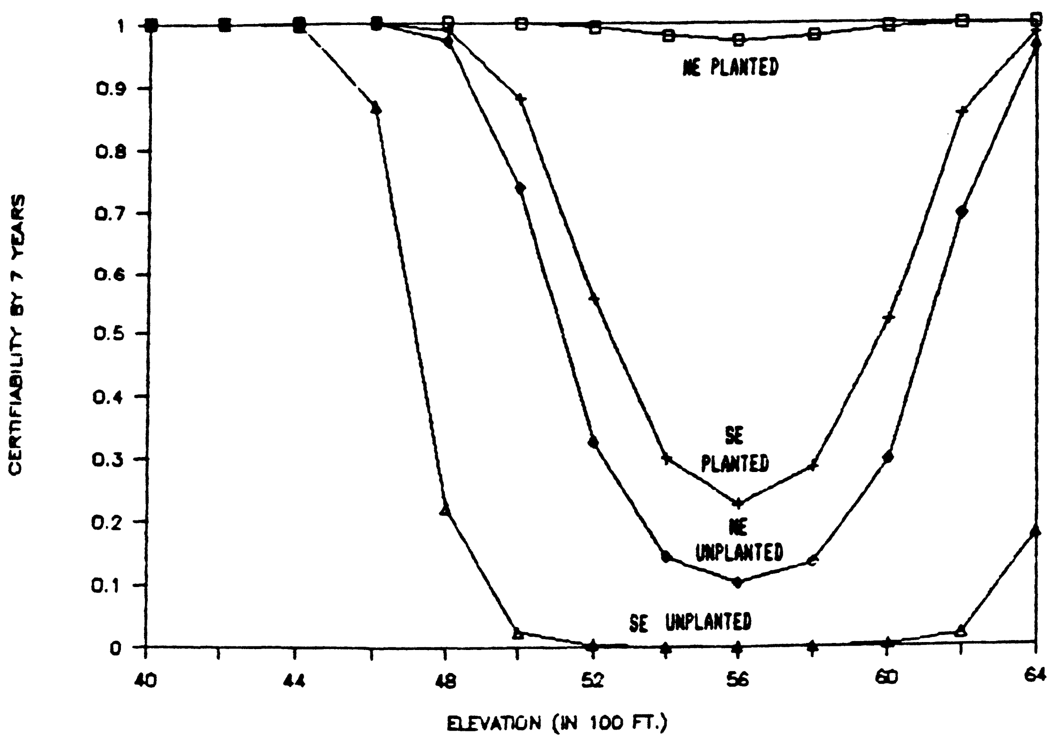

Figure 18 Certifiability by 7 Years After Harvest by Elevation, Aspect and Planting Schedule (35% slope)

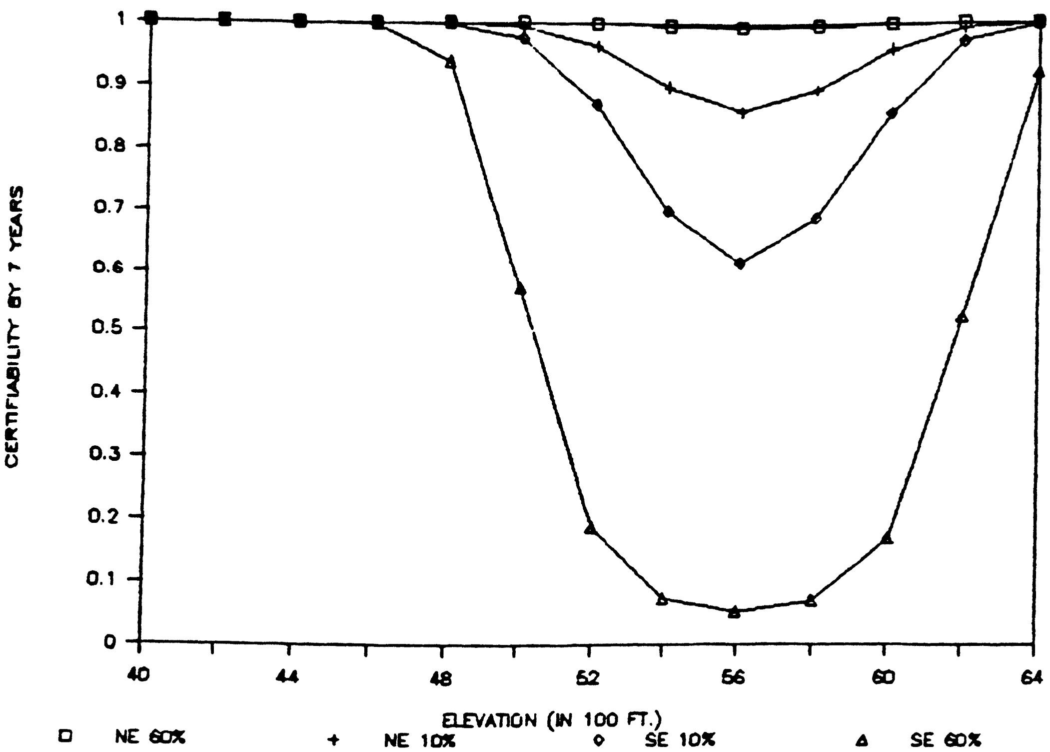

Figure 19 Certifiability by 7 Years After Harvest by Elevation, Slope and Aspect
(DIST_TO_PLNT = 2 and PLNT_TO_EXAM = 3)

Figure 20 shows the effects of slope, aspect and planting (planted stands with DIST_TO_PLNT = 2 and PLNT_TO_EXAM = 3, unplanted stands with both variables = 0) at the average elevation for this data set. It suggests that waiting to plant on SE aspects has a low probability of certifiability, especially on steeper slopes. The model also indicates that NE aspects at the middle elevations (which are primarily PSME habitat types) are unlikely to regenerate promptly unless planted.

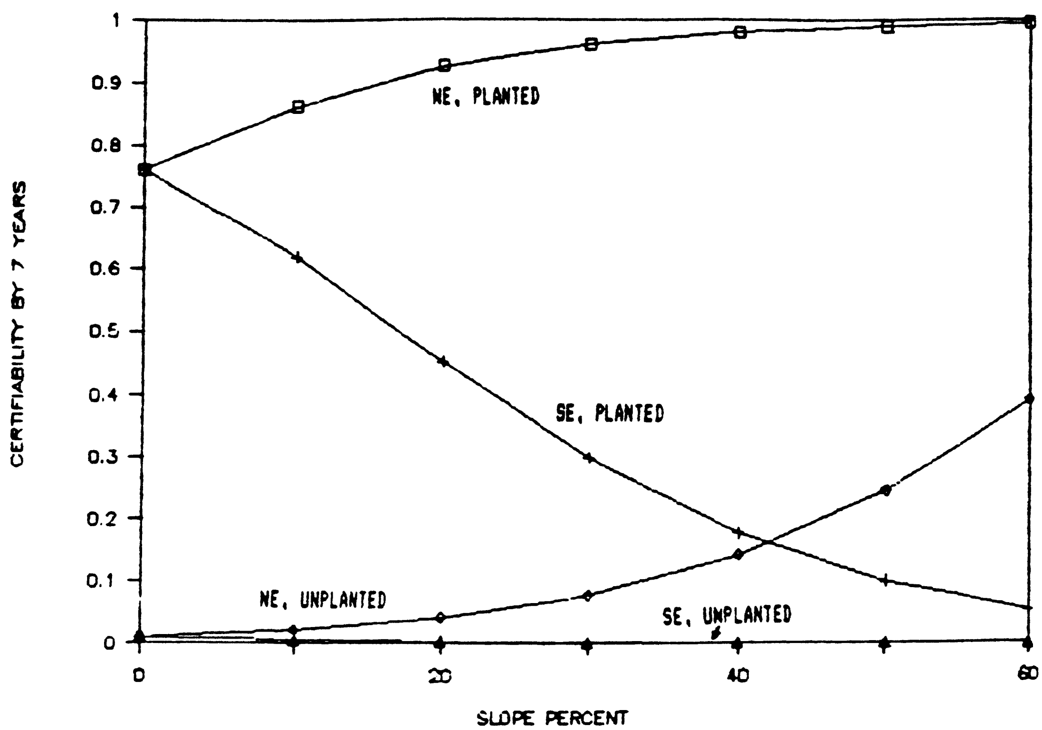

Figure 20 Certifiability at 7 Years After Harvest by Aspect, Slope, and Planting (elevation = 5550 feet)

Chapter 10

Conclusions and Recommendations

During the course of this study, I spent much time compiling and analyzing regeneration data, and also had the opportunity to discuss the processes of reforestation with many people, including Forest Service employees at several offices in U.S.F.S. Region 1. From the analyses and the discussions, I arrived at two major conclusions.

My first conclusion is that the five-year regeneration limit specified by the National Forest Management Act (NFMA) for harvestable timber stands on Forest Service lands[73] was not met on a majority of the stands analyzed in this study, and is not likely to be met on drier forest sites of the Missoula District, Lolo National Forest.

More than half of the stands harvested from 1980 through 1982 on the Missoula District did not regenerate to certifiable levels within 5 years after disturbance, nor within 7 years after harvest, regardless of whether they were planted or not. Most of those which did regenerate within either or both of the two time periods were stands on mesic sites, i.e., ABLA (subalpine fir) habitat types and/or northeast slopes.

As a complete population of areas harvested on the district within a three-year period, the study stands represent several types of sites which are presently considered suitable for timber management on the Lolo National Forest. The prescriptions and treatments for them were not unconventional or contradictory to recent silvicultural practices.

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[73]U.S. Congress (1976) National Forest Management Act, 90 Stat. 2949, Sec. 6(g)(3)(D).

Results from the weather analyses discussed in Chapter 6 indicate that there were several identifiable periods when the weather was appreciably beneficial or detrimental to regeneration establishment. However, except for above-normal moisture after the eruption of Mount St. Helens in May of 1980, the cycle of weather conditions from 1980 to 1988 was not unusual for this area.

Cone crop records from 1978 to 1988 for Douglas-fir (the species which was predominantly regenerated on the study stands) included 4 good, 4 poor and 3 fair crops. This distribution agrees with the cone crop periodicity reported in Boe (1954) from 22 years of records in Montana. Predictions of Douglas-fir cone crop intensities from several published studies relating cone crops to climatic influences were very similar to those observed from 1978 to 1988 (see Chapter 6).

Fiedler (1982) found average lengths of natural regeneration periods on PSME/VAGL and PSME/PHMA sites in western Montana to be at least 10 to 15 years. McQuillan (1981) reported that establishment of natural regeneration can take up to 20 years or more on dry PSME (Douglas-fir) habitat series sites in this area.

The findings from this study are not unusual or unexpected. What is interesting is how the rates of regeneration in the models change for different site conditions.

Table 13 summarizes some of the results from NATMOD, the model which estimated effective trees per acre for natural regeneration only on both planted and unplanted stands. The results from NATMOD are discussed in more detail and presented graphically in Chapter 7.

Table 13

Time to Certification for Typical Prescriptions of Effective Trees Per Acre by Site Characteristics (unplanted stands)

Prescribed Trees Per Acre	Years from Harvest*	Site Characteristics**
300	8	NE, ABLA HTs, 5500 ft., 60% slope
300	>8	NE, ABLA HTs, 6000 ft., 36% slope
300	>>8	SE, ABLA HTs, 6000 ft., 36% slope
200	6	NE, ABLA HTs, 5500 ft., 35%+ slopes
200	7	NE, ABLA HTs, 6000 ft., 36% slope
200	7.5	NE, PSME HTs, 5500 ft., 50%+ slopes
200	7.5	NE, PSME HTs, 5000 ft., 35%+ slopes
200	>8	SE, ABLA HTs, 6000 ft., 36% slope
150	8	SE, PSME HTs, 5500 ft., 0-35% slope
150	8	SE, PSME HTs, 5000 ft., 36% slope

* assumes 1 year between harvest and disturbance
** unburned; NE = northerly aspects, SE = southerly aspects
> = greater than   >> = much greater than

Table 14 summarizes results from NAPLMOD, the model which estimated effective trees per acre, including both natural and planted regeneration; the summary was derived from the graphs in Chapter 8.

Table 14

Time to Certification for Typical Prescriptions of Effective Trees Per Acre by Site Characteristics (for planted stands, average initial plant of 340 trees per acre)

Prescribed Trees Per Acre*	Years from Harvest**	Site Characteristics***
300	>8	NE, ABLA HT, all slopes
300	>>8	SE, ABLA HT, all slopes
200	6	NE, ABLA HT, all slopes
200	6	SE, ABLA HT, 35% slope
200	8	NE, PSME HT, 35% slope
200	>>8	SE, PSME HT, 35% slope
150	6	SE, PSME HT, 10% slope
150	>8	SE, PSME HT, 35% slope
150	>>8	SE, PSME HT, 60% slope

* natural and planted seedlings at least 6" tall and 3 years old
** 1 year between harvest and disturbance,
1 year between disturbance and planting
*** NE = northerly aspects, SE = southerly aspects

As Tables 13 and 14 show, only the best sites, either planted or unplanted, are expected to reach prescription levels of 200 trees per acre or less within six years after harvest (five years after disturbance). The study time frame for the two data sets (up to 8 years after harvest) was not long enough to ascertain how long it might take natural regeneration on the harsher sites to become established.

The findings from the LOGIT models (DIST5CERT and HARV7CERT, discussed in Chapter 9) also indicate that the 5-year time limit for regeneration establishment is not generally achievable on dry (PSME) sites unless they are planted. In DIST5CERT, only upper elevation ABLA habitat types (which were more often and more successfully planted than middle elevation stands) and a few lower elevation stands with unusual characteristics showed probabilities of certifiablity greater than .50 by five years after disturbance (see Chapter 9 for model results).

The model for certifiability by 7 years after harvest (HARV7CERT) indicated that plantations on northeast aspects have consistently high probabilities at all elevations, and unplanted southeast aspects have consistently low probabilities. Probabilities for planted stands on southeast aspects steadily decreased as slope percent increased. Both of the probability models had coefficients significant at least at the .05 level, but the amount of unexplained variation was high.

This leads to my second conclusion from this study, which is that the inevitability of unexplained variation in the reforestation process underscores the necessity for continued observation of harvested sites over time. Managerial insight about tree regeneration, gained from feedback between experience and research, depends as much on field reconnaissance as it does on statistical models. On the other hand, predictions of stocking densities and probabilities using either an experimental or retrospective statistical approach are at least as reliable as, and certainly enhance, subjective impressions and memories.

Communication between forest technicians, managers, planners, and researchers is essential. During the course of this study, I made a list of suggestions for improving regeneration surveys, and for creating and implementing realistic policies related to regeneration:

A. Technicians

1. Continue training in habitat type identification.
2. If retrospective studies such as this one are considered useful, take plot (vs. walk-thru) exams periodically on all regeneration harvests until certified as established, and calculate effective stocking according to the method suggested by Stage (1974) and described in Chapter 3.
3. Increase the number of plots on small stands in order to reduce the standard error of trees-per-acre estimates.
4. Record seedling heights, either the average height on each plot or the height of each tree tallied.
5. Identify stressed seedlings, especially those with dead tops.
6. Note inhibiting conditions on and around each plot.
7. Delineate regeneration problem areas on stand maps.
8. Record observations of cone crops and counts of new seedlings.

9. Establish and enforce quality control standards (including rigorous training) for survey and planting crews, regardless of whether they are contracted or employed by the Forest Service.
10. Conduct and keep records of plantation survival studies.
11. Keep records of annual cone crops on file at each District office and at the Forest Supervisor's office.
12. Maintain survey records: keep paper copies of exams in stand folders and update appropriate fields in the data base.

B. Managers

1. Write site-specific prescriptions based on site productivity and regeneration potential.
2. Evaluate carefully the U.S.F.S.Regeneration Status Reports and Reforestation Indices.
3. Stay informed about results from site-specific regeneration studies.
4. Provide for planting in the budget, but carefully evaluate the potential for natural regeneration before deciding to plant (determine regeneration probabilities and define RISK as outlined in Christopherson and Applegate, 1987).
5. Be aware of cyclical cone crop intensities and keep annual records of them for all species.
6. Attempt to forecast cone crops prior to harvest from weather conditions (see Chapter 6), and from ovulate bud observations (Allen, 1941; Roe, 1966; and Edwards, 1985).

7. Allow for flexibility in timing of harvests and treatment activities based on predictions of cone crops.
8. Apply broadcast burns with care, especially on dry sites, and follow with planting unless a good seed crop is anticipated.
9. Avoid dysgenic practices, i.e., treatments which may result in perpetuation of undesirable genetic characteristics, such as harvesting phenotypically outstanding trees or using only cull residuals for seeding and shading.

C. Planners

1. Stay in touch with management about observed regeneration establishment rates and treatment results.
2. Set rotation lengths which incorporate realistic regeneration rate estimates for all tree species, and calculate allowable cut volumes accordingly.[74]
3. Adjust yield tables to account for the effect of regeneration delays on estimates of basal area at expected entry age.
4. In determining acreage suitable for timber management, either abide by the NFMA five-year regeneration requirement, or change it through legislation to standards based on actual regeneration timing for each species and habitat type.

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[74] Determinations of allowable cuts are based on sustainable yields; calculations of sustainable yields require estimates of rotation lengths. Instead of adding an arbitrary regeneration lag of five years to rotation lengths on land suitable for timber management (as is presently done in the Lolo National Forest planning process), more realistic regeneration lags should be assigned according to productivity class, habitat type, slope, aspect, elevation, and/or treatment.

D. Researchers

1. Begin and continue long-term experimental studies on regeneration harvests, such as those described in DeByle (1981) and Shearer (1984, 1986).
2. Conduct retrospective studies of tree regeneration, and refine methods for analyzing data from them.
3. Examine the relationship between past weather events and cone crop cycles.

Public attention is increasingly focused on the legal and social obligations of the U.S. Forest Service to contribute to timber supplies while simultaneously providing for other forest resources on National Forest System lands. The forest products industry is becoming more dependent on timber from public forests to keep mills at full operating capacity. At the same time, interests which potentially conflict with timber harvesting, such as recreation, wildlife habitat and wilderness, continue to influence public forest management decision-making.

Reliable estimates of timber regeneration rates will not by themselves resolve conflicts between the various interest groups, but they are useful for identifying forest lands which are potentially suitable for intensive timber management. I hope that the findings from this study will in some way contribute to this important step in the process of intelligently using our forests.

APPENDIX A

Lolo National Forest Habitat Type Groups and Codes
(Revised in 1985 from On and Losensky, 1976)

Group 0	001-080 Non-forest types	
Group 1	130 PIPO/AGSP	230 PSME/FESC
	170 PIPO/SYAL	311 PSME/SYAL-AGSP
	210 PSME/AGSP	321 PSME/CARU-AGSP
	220 PSME/FEID	
Group 2	250 PSME/VACA	312 PSME/SYAL-CARU
	260 PSME/PHMA	313 PSME/SYAL-SYAL
	261 PSME/PHMA-PHMA	322 PSME/CARU-ARUV
	262 PSME/PHMA-CARU	324 PSME/CARU-PIPO
	310 PSME/SYAL	340 PSME/SPBE
Group 3	280 PSME/VAGL	323 PSME/CARU-CARU
	281 PSME/VAGL-VAGL	330 PSME/CAGE
	282 PSME/VAGL-ARUV	360 PSME JUCO
	292 PSME/LIBO-CARU	370 PSME/ARCO
	320 PSME/CARU (major phase is CARU-CARU)	
Group 4A	520 ABGR/CLUN	
	530 THPL/CLUN	
	570 TSHE/CLUN	
Group 4B	420 PIEN/VACA	630 ABLA/GATR
	440 PIEN/GATR	660 ABLA/LIBO
	470 PIEN/LIBO	670 ABLA/MEFE
	620 ABLA/CLUN	
Group 4C	550 THPL/OPHO	
	610 ABLA/OPHO	
	650 ABLA/CACA	
Group 4D	510 ABGR/XETE	291 PSME/LIBO-SYAL
	590 ABGR/LIBO	293 PSME/LIBO-VAGL
	290 PSME/LIBO	
Group 5	640 ABGR/XETE	720 ABLA/VAGL
	663 ABLA/VASC	731 ABLA/VASC-CARU
	690 ABLA/XETE	920 PICO/VACA
	710 TSME/XETE	
Group 6	730 ABLA/VASC	830 ABLA/LUHI
	732 ABLA/VASC-VASC	850 PIAL/ABLA
	820 ABLA(PIAL)/VASC	870 PIAL

Habitat Type Groups for Study Stands

Dry Habitat Types = 210, 260, 261, 262, 280, 282, 283, 320, 322
Wet Habitat Types = 590, 620, 640, 670, 690, 691

APPENDIX B

REGENERATION STOCKING GUIDELINES

U.S. Forest Service Region 1 Guidelines

The Northern Region (U.S. Forest Service Region 1) guidelines for regeneration stocking levels have been revised several times since 1980; except for changes in the accompanying narratives, the guidelines have remained essentially the same as the following table, which is printed below as it appeared in the Forest Service Manual in 1980 (FSM 2472.03-1 4/80 R-1 SUPP 254):

Northern Region Stocking Guides

Habitat Types with Productivity Estimates of:	Desired Trees/Acre	Minimum Trees/Acre for Certification
120+ *	450-600	300
50-119	300-600	200
20-50	200-600	100

*cu.ft./acre/year

In 1983, the guidelines were reprinted in FSM 2472.03--1 9/83 SUPP 307, without the minimum trees-per-acre for certification:

Northern Region Stocking Levels at 5 Years

Habitat Types with Productivity Estimates of:	Trees/Acre
120+	450-600
50-119	300-600
20-50	200-600

In 1985, the above guidelines were reprinted in the Forest Service Reforestation Handbook (FSH 2409.26b 4/85 AMEND 27 212--2) with the 1980 title, "Northern Region Stocking Guides," and were given as "generally acceptable ranges of stocking levels in regeneration practices."

In 1988, an amendment to the Forest Service Reforestation Handbook (U.S.D.A. Forest Service R-1 FSH 2409.26b 12/88 AMEND 36) had the same table as the 1983 and 1985 amendments, but added a statement about stocking distribution and the following sentence about preferred species: "seral species acceptable to the site should normally be favored."

Also in 1988, the height standard for regeneration was reduced to 6 inches; formerly it had been 2.5 feet on areas with potential brush inhibition or animal damage and 1.5 feet on areas unaffected by those factors.

All of the versions of the regional guidelines stress that the minimum number, distribution and species composition for certification must be specified in a site-specific silvicultural prescription, after considering habitat type, aspect, soils, site productivity, seed source type and proximity, available site preparation techniques, and potential mortality from animal damage, insects and disease. A stand may be certified when 90 percent of the reforestable area has met the prescribed stocking standards and the regeneration has survived at least three full growing seasons.

Lolo National Forest Guidelines

The following table of stocking level guides for the Lolo National Forest is from Christophersen and Applegate (1987), p. 22:

Lolo National Forest General Stocking Level Guides
Minimum Stocking Levels
(for certification at/near age 5)

Habitat Group[1]	Minimum Adequate Trees/acre	Percent Stocked Plots 1/300th[2]	Percent Stocked Plots 1\100th
2 & 3	175	50	70
4	275	60	80
5	250	55	75

[1] refer to Appendix A for habitat type groups
[2] plot size in acres

The habitat type groupings in the Lolo National Forest guidelines roughly correspond to the Region 1 productivity classes as shown in the following table (from Pfister, et al. (1977), p.169; U.S.F.S. Region 1 12/88 AMEND 36; and Christophersen and Applegate (1987), p.27 ff.:

Lolo National Forest Habitat Type Group	Productivity Class cu.ft./ac./yr
2 & 3	0-49
4	120+
5	50-119

As with the Regional guidelines, the Forest guidelines are not to be applied in the absence of a stand-specific analysis and prescription which takes into account site, stand and treatment conditions. "Minimum stocking must include the minimum number of acceptable trees per acre, the minimum number of stocked plots and have these trees distributed uniformly over the site. Species diversity is also important and should be specified in the silvicultural prescription" (Christophersen and Applegate, 1987, p. 22).

APPENDIX C

Derivation and Calculation of Effective Stocking Percent (ESTK) and Effective Trees per Acre (ETPA) (adapted from Stage, 1974)

Formulas for Calculating ESTK and ETPA

From the general expression of the Poisson distribution, $\frac{\lambda^i e^{-\lambda}}{i}$, the following equations are used to calculate the probabilities of occurrence (Table C-1) for a given target number of trees-per-plot (the mean of the Poisson distribution, or λ, is the target):

$$Pr(0) = \frac{e^{-\lambda}}{1}$$

$$Pr(1) = \frac{\lambda(e^{-\lambda})}{1}$$

$$Pr(2) = \frac{\lambda^2(e^{-\lambda})}{2}$$

$$Pr(3) = \frac{\lambda^3(e^{-\lambda})}{6}$$

$$Pr(4+) = 1 - [Pr(0) + Pr(1) + Pr(2) + Pr(3)]$$

Table C-1

Probabilities of Occurrence of Numbers of Trees Per Plot

Target Trees/plot (λ)	Probability Values for Trees-per-Plot* (Pr(TPP)) Pr(0)	Pr(1)	Pr(2)	Pr(3)	Pr(4+)
1.2	.301	.360	.220	.087	.032
1.58	.206	.325	.257	.135	.077
1.8	.165	.298	.268	.161	.108
2.0	.135	.271	.271	.180	.143
2.3	.100	.231	.265	.203	.201
2.5	.082	.205	.257	.214	.243
2.6	.074	.193	.251	.218	.264
3.0	.050	.149	.224	.224	.353
3.5	.030	.106	.185	.216	.463
3.6	.027	.098	.177	.213	.485

*For any λ, Pr(0) + Pr(1) + Pr(2) + Pr(3) + Pr(4+) = 1

To prevent undue inflation from overly dense plots, an upper limit (n) is placed on the number of trees with less than .3 in the Poisson distribution, where n takes the following values:

λ	n
1.2 to 1.9	2
2.0 to 2.7	3
2.8 to 3.6	4

Defining x_i as the stocking percent for i trees/plot, with $x_1 = k$ and $x_0 = 0$, the following equation expresses the assumption that each additional tree represents two-thirds the stocking of the previous tree:

$$x_i = k \sum (2/3)^{j-1} .$$

Table C-2 was reproduced from Stage (1974); it shows the stocking percentages per plot for each number of seedlings on a plot given a target TPP, as calculated from the following formula:

$$\sum_{i=1}^{n-1} \frac{x_i \lambda^i e^{-\lambda}}{i!} + \sum_{i=n} \frac{x_i \lambda^i e^{-\lambda}}{i!} = 100.$$

Table C-2

Stocking Percentages Per Plot

Target trees/plot	Number of seedlings on a plot 0	1	2	3	4
1.2	0	108	180	180	180
1.4	0	98	163	163	163
1.5	0	95	159	159	159
1.6	0	90	150	150	150
1.8	0	84	136	136	136
2.0	0	71	119	150	150
2.3	0	66	109	138	138
2.6	0	61	102	130	130
3.0	0	54	90	114	130
3.5	0	50	83	105	121

The following two equations show how the effective stocking percent and effective trees per acre for a stand would be calculated using the values in Table C-2, given a target of 2.0 TPP (which would be the case, for example, if the prescribed TPA was 200 and the plot size was 1/100 acre):

1. Defining the number of plots with 1 tree per plot as NPT1, the number of plots with 2 TPP as NPT2, and so forth:

$$\frac{(NPT0 * 0) + (NPT1 * 71) + (NPT2 * 119) + (NPT3 * 150) + (NPT4+ * 150)}{\text{total number of plots}}$$

= effective stocking percent (ESTK);

2. ESTK x prescribed TPA = ETPA (Effective TPA)

Comparison of ESTK and ETPA with Traditional Measures

Table C-3 compares the results of calculations from example surveys of ten 100th acre plots for four different measures of stocking.

Table C-3

Comparison of Trees per Acre with Effective Stocking %
and Effective Trees per Acre
(From example surveys with 10 100th acre plots)

Example Survey #	Trees per Plot 0	1	2	3	4+	*STK%	ESTK	TPA	ETPA
1	9	0	0	1	0	10	15.0	30	30.0
2	1	0	9	0	0	90	107.1	180	214.2
3	5	1	3	0	1	50	57.8	110	115.6
4	5	2	2	1	0	50	53.0	90	106.0
5	5	5	0	0	0	50	35.5	50	71.0
6	3	0	3	3	1	70	95.7	190	191.4
7	3	3	0	3	1	70	81.3	160	162.6
8	3	5	0	1	1	70	65.5	160	131.0
9	3	3	3	1	0	70	72.0	100	144.0
10	3	7	0	0	0	70	49.7	70	99.4

*STK% = Stocking percent using 100th acre plots

ESTK = Effective stocking percent with a goal of 200 trees per acre (target = 2 trees per plot)

TPA = trees per acre (assuming 4 trees per plot maximum)

ETPA = Effective trees per acre with a goal of 200 trees per acre (ESTK x 200)

APPENDIX D

Site Characteristics and Activities of Study Stands

Stands Harvested 1980-82 on the Missoula R.D.

STAND #	HT	TRTMT ACRES	SLOPE	ASP	ELEV	HARV DATE	HARV TYPE	# RES	PREP DATE	SITE PREP	#PLOT EXAMS	# WT EXAMS	PLANT DATE	TPA PTD	RX TPA	5YRD STAT	7YRH STAT
30909019	260	15	10	SE	47	3/81	4131	10	8/83	SCAR	2	0			150	C	C
31201003	262	12	13	N	47	3/81	4131	16	8/83	SCAR	2	0			150	C	C
32201030	590	3	50	N	53	6/81	4132	5			0	1			200	C	C
32203032	640	5	8	SE	40	7/82	4111	0			1	1	5/83	250	200	C	C
32803004+	283	24	50	NE	54	6/81	4131	36			1	0			200	---	---
32803004	320	11	50	NE	54	6/81	4131	20			2	0	5/85	250	200	P	C
32803004	283	13	50	NE	54	6/81	4131	50			0	1			200	P	P
33001004+	320	27	50	E	51	9/81	4132	20	5/84	BURN	1	0			200	---	---
33001004	320	10	50	SE	51	9/81	4132	20	5/84	BURN	2	0	9/85	300	200	P	C
33001004	320	17	50	E	51	9/81	4132	20	5/84	BURN	1	0			200	P	P
33001013	320	4	70	SE	50	9/81	4131	15			2	0			200	P	P
33001013	320	2	70	NE	50	9/81	4131	15			2	0			200	C	C
33002001+	261	36	50	NE	56	2/81	4132	5	8/84	BURN	1	0			200	---	---
33002001	261	12	50	NE	56	2/81	4132	5	8/84	BURN	2	0	5/87	450	200	P	P
33002001	261	24	50	NE	56	2/81	4132	5	8/84	BURN	1	0			200	P	P
33002002	280	7	50	NE	55	6/81	4132	15	10/81	BURN	3	1			200	P	C
33002002	260	6	50	SE	55	6/81	4132	5	10/81	BURN	3	1			200	P	P
33002004	262	23	50	E	54	5/81	4132	0	8/83	BURN	3	0	5/84	340	200	P	P
33002008+	260	12	40	SE	52	8/81	4131	10		#	2	0			150	---	---
33002008	261	2	40	SE	52	8/81	4131	10		#	0	1			150	EXCH	EXCH
33002008	262	10	40	SE	52	8/81	4131	10		#	1	0	9/85	300	150	EXCH	EXCH
33002027	280	11	35	N	52	5/81	4132	10	8/83	BURN	1	0			200	NE	P
33003001+	260	30	60	NW	43	10/80	4131	10	4/83	BURN	0	2			150	---	---
33003001	260	20	60	NW	43	10/80	4131	0	4/83	BURN	1	0	5/85	420	150	EXCH	EXCH
33003001	260	7	60	NE	43	10/80	4131	25	4/83	BURN	1	0	5/85	420	150	EXCH	EXCH
31102027	670	8	20	N	64	9/80	4113	0	10/81	SCAR	2	1	9/82	410	200	C	C
31102027	670	6	20	N	64	9/80	4113	0	10/81	SCAR	2	1			200	P	P
31102013	690	22	20	NW	64	9/80	4113	0	10/81	SCAR	2	1	9/82	350	200	C	C
31102012	670	35	20	N	62	9/80	4113	0	10/81	SCAR	2	1	9/82	350	300	C	C
31102012	670	8	20	N	62	9/80	4113	0			2	1			300	C	C
31102008	670	30	20	N	60	9/80	4113	0		#	2	0	9/86	250	300	P	P
31102008	670	15	20	N	60	9/80	4132	2		#	2	0	9/86	250	300	P	P
31007029	691	3	40	NE	64	6/80	4113	0	10/81	SCAR	2	1	5/83	350	200	P	C
31007026	670	50	20	NW	64	6/80	4113	0	10/81	SCAR	2	0	9/84	330	200	C	C
31007022	670	20	25	N	59	9/80	4132	5	9/85	SCAR	1	0			200	NE	P
31007022	691	23	25	N	59	9/80	4132	1	9/85	SCAR	1	0	9/86	400	200	C	P
31007017	620	5	30	NW	62	9/80	4132	2	8/85	SCAR	1	0	5/86	300	200	P	P
31007017	620	40	30	NW	62	9/80	4132	10	8/85	SCAR	1	0			200	C	C
34101010+	280	38	20	LR	57	9/81	4132	5	9/82	SCAR	0	1			200	---	---
34101010	690	19	20	LR	58	9/81	4132	0	9/82	SCAR	1	1	5/84	300	200	NE	NE
34101010	280	19	20	LR	56	9/81	4132	10	9/82	SCAR	0	2			200	NE	NE
34102012	670	20	20	NE	61	6/81	4113	0	9/82	SCAR	1	1	5/84	300	200	C	C
34102015	670	10	10	LR	58	9/81	4110	0	9/82	SCAR	0	1			300	P	P
34102015	670	32	10	LR	58	9/81	4132	7	9/82	SCAR	0	1			300	P	P
34102018	691	2	20	N	60	9/81	4132	5			0	1			300	C	C
37701007	322	5	10	NW	54	7/80	4131	2	9/83	SCAR	1	0			200	P	P
37804016	261	12	40	NW	50	8/81	4132	5			1	0			300	P	C
37804003	280	4	35	NE	52	8/80	4132	10	9/83	SCAR	1	0			300	C	C
37804017	690	11	35	N	54	7/80	4131	5	9/83	SCAR	1	0			200	P	P
37804026	283	5	8	NE	54	7/80	4110	2	9/83	SCAR	1	0			200	NE	P
37804026	283	3	8	NE	54	7/80	4110	2	9/83	SCAR	1	0	4/87	300	200	NE	P
33601019	282	27	20	N	48	9/80	4131	33	10/80	SCAR	1	0			150	P	NE
31102028	670	21	10	NE	63	9/80	4113	0	9/81	SCAR	2	1	9/82	350	200	C	C
32707015+	260	13	50	E	48	9/80	4132	5	4/84	BURN	1	0	9/84	300	200	---	---
32707015	260	10	50	E	48	9/80	4132	5	4/84	BURN	1	0	9/86	400	200	NE	P
32707015	260	3	50	E	48	9/80	4132	0	4/84	BURN	1	0	9/86	400	200	NE	P
33002010	210	22	40	SE	51	6/80	4132	7	11/81	BURN	2	0	5/84	300	200	P	P
33002005	260	11	50	E	51	6/81	4132	5			2	0			150	P	EXCH
33002005	260	11	50	E	51	6/81	4131	15			1	1			150	P	EXCH
33002007	260	4	60	NE	52	6/81	4131	20		#	2	1	9/85	300	150	P	P
33002007	260	7	40	NE	50	6/81	4131	10		#	2	1	9/85	100	150	P	P

KEY

(+ denotes a parent stand divided into substands)

HARV TYPE CODES
4110 = clearcut
4131 = shelterwood cut
4132 = seed tree cut

SITE PREP CODES
SCAR = scarified
BURN = broadcast burn
# = ineffective burn

RX TPA = prescribed TPA
5YRD STAT = regen status at 5 years after disturbance
7YRH STAT = regen status at 7 years after harvest
C = certifiable P = progressing
EXCH = land exchange

# RES = leave trees per acre WT = walk-thru
NE = no available exam at either 5YRD or 7YRH

Appendix E

Initial Inquiry

My initial inquiry during this study was on stands harvested from 1965 to 1983 on the Missoula, Superior, Plains and Seeley Lake Ranger Districts of the Lolo National Forest. Over 500 stands were stratified by nine habitat types. Although there were a lot of data available, there were several aspects of the data set which created difficulties in the analysis.

The first problem with the data was that regeneration surveys on those stands had been conducted by numerous people; most of the examiners, and their levels of experience, were unknown to me, causing some concern about measurement bias. Secondly, the survey reports had differing formats, making it difficult to define dependent and independent variables with any consistency. A third problem was with stands which had been coded as regeneration harvests, but had surveys showing more than 50 residual trees per acre.

The major problem was that intensive monitoring of regeneration did not begin until the late 1970's, over 10 years after the beginning year (1965) of the initial inquiry. Many of the stands had adequate regeneration by the time they were surveyed (which in some cases was 10 to 15 years after harvest), but there was no information on when they had actually become certifiable. Several stands cut in the early 1970's were still not certifiable by the 1980's, even though they had been planted at least once. The lack of consistent survey data from the early years of regeneration after harvest, especially on planted stands, did not bode well for modelling the rate at which regeneration becomes established.

Indeed, the regression equations for this initial data set had a lot of unexplained variation (the R-squared values of the early models were .30 at best). Realizing that the data from these harvests were not amenable to developing useful regeneration models, and that it would be more meaningful to analyze stands harvested after the NFMA and its regulation had been in effect, I then narrowed the time frame and restricted the study to one district. The resulting data set was comprised of exams from 1980 to 1982 regeneration harvests on the Missoula Ranger District of the Lolo National Forest.

APPENDIX F

Timber Stand Management Record System (TSMRS) Queries

1. Decide what activities and years to query for (check the Timber Stand Management Control Handbook for codes and formats).

2. Decide whether you want:
   a. only certain fields of information in the output (1-step process), or
   b. the more complete output available on Forms 21-24 (a 2-step process).

3. For 2a, write a query, such as the following:

```
LIST C1,C407,C10,C18,C25, OB C1 WH C402 EQ 4110*4142 AND C407 EQ
1980*1988:
```

This asks for stands with regeneration harvests from fiscal year 1980 to 1988 (10/79 thru 9/88), listed by stand ID (field 1 on Form 21), accomplishment year (field 407 on Form 24), stand acres (field 10 on form 21), habitat type (field 18 on Form 21) and management area (field 25 on Form 21).

The width of the computer form is 131 columns; if you ask for more than about 10 fields, it wraps around and gets messy, so you might be better off getting the complete Forms.

You may request the above info by harvest year (or any attribute) instead of stand ID, or create nested ordering (e.g., OB C1,C407 WH...).

The proper placement of punctuation is critical.

After creating the query language file, get into the TMSTAND runstream generator menu and select #16 - Query Timber Stand Data Base (TSMRS). One of the things it will ask for is the input file name. When finished, the runstream can be queued up immediately to send to FCCC. It is cheaper to run overnight, but if run during the day, it should cost less than $5.00. The output comes back in a file named B_(10 digits)_Q which I like to rename so I can work with it more easily if I want to edit it or send it to someone.

4. For 2b, write a query just for a stand listing, like this one:

```
LIST C1 WH C402 EQ 4110*4142 AND C407 EQ 1980*1982:
```

Go through the same process as in 3 above, and then edit the output file as follows:

1. Delete the query language at the top.

2. Delete the asterisks so that the stand number starts in column 1.

3. Add the 2-digit Forest code (e.g., 16 for Lolo NF, 02 for Beaverhead NF) in columns 9 and 10.

4. If you want only certain forms instead of all of them, put a 1 in column 12. A 1 in column 13 is for Forms 21 and 22, a 1 in column 14 is for Form 23 and a 1 in column 15 is for Form 24. Leave columns 12-15 blank to get all Forms.

5. After editing the output file in 4., go back into TMSTAND and select menu #6-New Form 21-24 Listing. It will ask for the input file name and whether you want a master list or individual Forms for each stand- choose the master list.

6. The query for harvested stands which have not been planted is:

   LIST C1 WH CO HAS C402 EQ 4110*4142 AND NOT CO HAS 402 EQ 4430*4442:

Appendix G

Weather Data

Monthly Precipitation
Western Montana Division
(from NOAA, 1959-1988)

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANN
1959	3.05	1.60	1.13	1.66	2.69	1.78	0.17	1.16	3.51	2.74	3.23	0.76	23.48
1960	1.26	1.14	1.61	1.47	2.29	0.86	0.19	2.21	0.58	1.15	2.74	1.01	16.51
1961	1.27	2.54	1.67	2.31	3.09	0.92	0.83	0.78	2.33	1.84	2.06	2.57	22.21
1962	1.49	1.07	1.71	1.39	2.78	1.31	0.67	1.11	1.16	2.21	2.38	1.64	18.92
1963	1.72	1.92	1.69	1.05	0.99	3.58	0.67	0.76	1.61	1.25	1.76	1.66	18.66
1964	2.54	0.83	1.76	1.50	2.00	3.40	1.76	1.71	1.36	1.24	2.18	5.01	25.29
1965	2.51	1.48	0.66	2.43	1.23	2.58	1.16	2.65	2.32	0.28	1.96	1.27	20.53
1966	2.57	1.20	1.39	0.73	1.29	3.52	0.90	1.49	0.54	1.38	2.86	1.83	19.70
1967	3.20	1.35	1.68	1.24	1.67	2.42	0.34	0.08	0.56	3.34	1.27	2.12	19.27
1968	1.58	1.59	1.03	0.94	1.75	2.14	0.56	2.56	3.47	1.81	1.71	2.42	21.56
1969	4.38	0.65	0.83	1.11	1.57	3.88	0.47	0.06	1.48	1.29	0.52	1.53	17.77
1970	3.67	1.42	1.52	1.45	1.95	2.48	1.93	0.49	1.43	1.35	2.18	2.11	21.98
1971	3.79	1.30	1.57	1.42	2.14	2.63	0.87	1.13	0.82	1.17	1.58	2.74	21.16
1972	3.59	3.02	1.84	1.29	1.32	1.82	1.28	0.98	1.48	1.30	0.76	2.46	21.14
1973	1.24	0.45	0.72	0.73	1.11	1.92	0.12	0.57	1.41	1.17	4.09	2.60	16.13
1974	4.23	1.59	2.37	1.34	1.31	1.48	1.10	1.17	0.78	0.26	1.91	1.60	19.14
1975	2.77	2.21	1.47	1.51	1.71	2.00	1.52	2.61	0.71	3.55	1.86	2.32	24.24
1976	1.78	2.06	0.88	1.21	1.55	2.09	1.40	2.78	0.87	0.51	1.06	0.72	16.91
1977	0.99	0.64	1.43	0.22	2.05	0.89	1.61	1.56	2.30	0.94	2.37	4.39	19.39
1978	1.95	1.08	0.84	1.72	2.90	1.14	2.06	1.98	1.56	0.34	1.70	1.73	19.00
1979	1.26	2.33	1.08	1.40	1.21	0.68	0.57	1.46	0.33	1.46	0.41	2.10	14.29
1980	2.17	1.19	1.36	1.25	4.96	3.41	1.44	1.46	1.66	0.94	1.72	3.28	24.84
1981	0.75	1.80	1.14	1.57	3.84	3.58	1.16	0.73	1.05	0.85	1.75	2.42	20.64
1982	2.80	2.54	1.91	1.93	1.65	2.44	1.75	0.87	1.83	1.19	1.65	2.16	22.72
1983	1.79	1.33	1.59	1.14	1.42	2.63	2.75	1.37	1.48	0.96	2.47	1.75	20.68
1984	1.30	0.71	1.48	1.80	2.49	2.35	0.59	1.30	1.66	1.71	2.01	1.93	19.33
1985	0.27	1.16	0.72	1.08	1.96	1.48	0.14	2.24	3.98	1.83	1.97	0.50	17.33
1986	1.98	2.72	0.99	0.97	2.03	2.06	1.40	1.31	2.94	0.74	2.60	0.61	20.35
1987	0.79	0.85	2.06	0.88	1.95	1.83	3.05	1.31	0.29	0.09	0.71	1.77	15.58
1988	1.16	1.01	1.40	1.57	2.65	1.76	0.76	0.30	1.34	1.28			

Average Monthly Temperatures
Western Montana Division
(from NOAA) 1959-1988

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANN
1959	24.6	23.0	34.7	43.1	46.8	58.8	64.5	60.3	52.0	43.1	26.1	26.6	42.0
1960	18.0	24.6	32.3	42.1	48.9	57.8	68.7	59.9	55.0	44.3	32.5	23.5	42.3
1961	26.4	34.9	36.1	40.5	51.0	63.2	66.3	67.9	48.9	41.8	28.1	22.7	44.0
1962	17.2	26.3	31.1	45.2	49.5	57.2	61.9	61.5	54.0	44.4	35.5	31.3	42.9
1963	12.2	33.5	36.5	42.3	50.9	57.8	62.5	64.3	59.2	47.6	35.0	22.9	43.7
1964	26.6	27.8	30.3	40.8	49.3	56.9	64.6	59.1	51.0	44.0	32.4	21.0	42.0
1965	27.9	23.8	26.6	44.0	48.7	56.7	64.1	63.0	46.5	47.1	35.0	27.5	43.0
1966	25.5	27.7	33.6	41.7	53.2	55.4	64.7	62.3	59.2	43.7	33.4	29.3	44.1
1967	30.0	32.2	32.1	38.7	49.9	58.4	66.0	67.4	61.3	45.1	32.7	23.1	44.7
1968	22.6	32.0	39.8	40.3	49.0	57.5	64.9	61.2	53.9	42.3	33.2	20.6	43.1
1969	15.6	24.2	30.9	45.9	53.3	57.8	62.2	64.2	55.7	39.9	33.9	27.1	42.6
1970	23.1	31.5	32.3	38.4	51.8	61.8	66.2	64.7	49.8	40.8	32.0	24.4	43.1
1971	24.8	29.7	32.5	42.8	52.5	55.9	63.1	68.1	50.2	41.2	33.5	21.5	43.0
1972	19.6	28.3	38.7	40.0	51.6	59.3	62.0	65.9	51.3	41.4	33.1	19.1	42.5
1973	21.0	28.4	37.4	41.8	51.9	58.2	65.7	65.2	54.5	44.4	29.5	29.7	44.0
1974	20.6	32.3	34.2	44.3	47.5	62.3	64.8	62.4	54.4	45.5	34.7	28.9	44.3
1975	23.3	22.8	30.9	37.2	48.2	55.1	68.6	59.9	54.3	43.1	30.3	27.7	41.8
1976	27.4	29.6	31.0	43.3	53.1	55.1	64.6	61.9	56.6	43.7	33.3	27.9	44.0
1977	20.3	32.2	34.1	45.9	49.4	61.5	63.0	63.4	52.8	43.6	30.6	23.7	43.4
1978	23.7	28.5	37.5	44.0	48.2	58.8	63.7	61.2	54.6	45.0	26.6	17.1	42.4
1979	5.8	26.8	35.8	42.6	51.7	59.7	65.5	65.4	57.8	46.5	28.2	31.1	43.1
1980	16.3	29.3	32.7	47.4	53.8	57.0	63.4	59.0	54.8	45.0	34.4	30.8	43.7
1981	29.8	30.8	38.6	44.6	51.7	54.7	62.9	66.6	55.5	42.7	35.0	26.0	44.9
1982	21.7	23.8	36.0	39.3	49.6	59.9	62.3	64.0	53.8	42.9	29.3	24.0	42.2
1983	30.1	33.8	38.6	42.7	51.7	58.0	61.4	66.8	51.3	44.4	35.4	12.2	43.9
1984	26.8	32.7	38.3	43.1	49.2	56.7	65.4	65.5	51.0	40.8	32.7	20.6	43.6
1985	19.3	21.9	33.2	45.5	53.7	58.7	69.7	61.0	49.7	41.2	19.9	18.5	41.0
1986	27.8	27.8	41.0	43.7	53.2	63.7	60.2	66.7	50.9	44.6	30.6	24.1	44.5
1987	22.7	30.2	36.6	48.6	54.8	61.3	63.3	60.3	56.9	44.5	35.2	24.6	44.9
1988	21.7	31.0	37.3	47.0	52.4	62.4	64.6	64.2	55.0	48.9			

Monthly Precipitation- Western Montana Division
Period Normals and Pooled Sample T-tests

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANN
31-60 NORM	21.8	25.8	33.0	43.2	51.5	57.5	64.9	62.8	54.6	44.7	32.1	26.2	43.2
41-70 NORM	21.6	27.8	32.5	42.6	50.9	57.3	64.4	62.9	54.2	44.1	32.3	25.4	43.0
51-80 NORM	21.7	27.4	32.9	42.2	50.8	57.8	64.4	62.9	54.2	43.8	31.9	25.6	43.1
AVG 59-88	22.41	28.71	34.69	42.89	50.88	58.59	64.36	63.44	53.73	43.78	31.80	24.40	43.27
S 59-88	5.477	3.642	3.375	2.756	2.113	2.493	2.184	2.743	3.342	2.120	3.519	4.534	0.996
AVG 62-70	22.3	28.8	32.6	41.9	50.6	57.7	64.1	63.1	54.5	43.9	33.7	25.2	43.2
S 62-70	6.05	3.64	3.79	2.69	1.77	1.75	1.59	2.41	4.88	2.59	1.25	3.74	0.81
AVG 71-79	20.7	28.7	34.7	42.4	50.5	58.4	64.6	63.7	54.1	43.8	31.1	25.2	43.2
S 71-79	6.13	2.87	2.87	2.56	2.13	2.63	1.95	2.62	2.38	1.77	2.73	5.01	0.83
AVG 80-88	24.0	29.0	36.9	44.7	52.2	59.2	63.7	63.8	53.2	43.9	31.6	22.6	43.6
S 80-88	4.83	3.94	2.67	2.85	1.90	2.92	2.74	2.99	2.53	2.41	5.19	5.51	1.35

95% ONE-TAILED T-TESTS Ho:D=0

1959-88 vs. 1980-88 Critical t-value = 1.645

X1-X2:	-1.609	-0.320	-2.232	-1.762	-1.350	-0.569	0.671	-0.346	0.519	-0.106	0.234	1.797	-0.320
Sp:	28.6	13.8	10.5	7.7	4.3	6.7	5.4	7.8	10.1	4.8	15.2	22.5	1.2
t:	-0.792	-0.227	-1.815	-1.670	-1.717	-0.577	0.763	-0.325	0.429	-0.127	0.151	0.953	-0.779
Ho:	NO REJ	NO REJ	REJECT	REJECT	REJECT	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ
80-88:			WARMER	WARMER	WARMER								

1962-70 vs. 1980-88 Critical t-value = 1.746

X1-X2:	-1.722	-0.256	-4.344	-2.733	-1.611	-1.433	0.433	-0.711	1.300	-0.011	2.115	2.644	-0.343
Sp:	30.0	14.4	10.7	7.7	3.4	5.8	5.0	7.4	15.1	6.3	13.4	21.6	1.2
t:	-0.667	-0.143	-2.813	-2.092	-1.860	-1.262	0.410	-0.556	0.709	-0.009	1.190	1.170	-0.653
Ho:	NO REJ	NO REJ	REJECT	REJECT	REJECT	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ
80-88:			WARMER	WARMER	WARMER								

1971-79 vs. 1980-88 Critical t-value = 1.746

X1-X2:	-3.300	-0.300	-2.244	-2.222	-1.778	-0.722	0.867	-0.078	0.844	-0.067	-0.474	2.589	-0.416
Sp:	30.5	11.9	7.7	7.4	4.1	7.7	5.7	7.9	6.0	4.5	16.5	27.6	1.3
t:	-1.268	-0.185	-1.718	-1.738	-1.871	-0.550	0.773	-0.059	0.730	-0.067	-0.240	1.015	-0.786
Ho:	NO REJ	NO REJ	NO REJ	NO REJ	REJECT	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ
					WARMER								

Monthly Average Temperatures- Western Montana Division
Period Normals and Pooled Sample T-tests

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANN
31-60 NORM	1.81	1.11	1.35	1.25	1.82	2.26	0.99	0.96	1.29	1.63	1.87	1.96	18.66
41-70 NORM	2.09	1.45	1.31	1.36	1.97	2.54	1.03	1.15	1.43	1.76	2.01	2.01	20.01
51-80 NORM	2.35	1.54	1.33	1.35	1.97	2.21	1.06	1.32	1.38	1.45	1.87	2.19	20.02
AVG 59-88	2.128	1.493	1.384	1.344	2.052	2.169	1.107	1.340	1.561	1.339	1.913	2.000	19.955
S 59-88	1.089	0.668	0.430	0.452	0.861	0.894	0.738	0.749	0.948	0.814	0.800	1.025	2.744
AVG 62-70	2.629	1.279	1.363	1.316	1.692	2.812	0.940	1.212	1.548	1.572	1.871	2.066	20.403
S 62-70	0.983	0.391	0.418	0.488	0.528	0.837	0.567	0.972	0.901	0.840	0.677	1.204	2.278
AVG 71-79	2.400	1.631	1.356	1.204	1.700	1.628	1.170	1.582	1.140	1.189	1.749	2.296	19.044
S 71-79	1.228	0.846	0.536	0.456	0.577	0.631	0.584	0.744	0.598	0.985	1.071	1.002	2.993
AVG 80-88	1.446	1.479	1.406	1.354	2.550	2.393	1.449	1.210	1.803	1.066	1.860	1.803	20.184
S 80-88	0.803	0.723	0.424	0.375	1.148	0.722	0.959	0.542	1.075	0.523	0.575	0.906	2.872

95% ONE-TAILED T-TESTS Ho:D=0

1959-88 vs. 1980-88 Critical t-value = 1.645

X1-X2:	0.683	0.014	-0.021	-0.011	-0.498	-0.225	-0.342	0.130	-0.242	0.273	0.053	0.198	-0.229
Sp:	1.069	0.463	0.183	0.191	0.866	0.739	0.626	0.503	0.955	0.579	0.573	1.001	7.687
t:	1.740	0.053	-0.131	-0.065	-1.411	-0.689	-1.138	0.482	-0.653	0.947	0.178	0.497	-0.207
Ho:	REJECT	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ
80-88:	DRIER												

1962-70 vs. 1980-88 Critical t-value = 1.746

X1-X2:	1.183	-0.200	-0.042	-0.039	-0.858	0.419	-0.509	0.002	-0.256	0.507	0.011	0.263	0.220
Sp:	0.805	0.338	0.177	0.189	0.799	0.611	0.621	0.619	0.984	0.489	0.399	1.155	6.720
t:	2.797	-0.730	-0.213	-0.190	-2.036	1.137	-1.370	0.006	-0.547	1.536	0.036	0.504	0.180
Ho:	REJECT	NO REJ	NO REJ	NO REJ	REJECT	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ
80-88:	DRIER				WETTER								

1971-79 vs. 1980-88 Critical t-value = 1.746

X1-X2:	0.954	0.152	-0.050	-0.150	-0.850	-0.766	-0.279	0.372	-0.663	0.123	-0.111	0.493	-1.139
Sp:	1.1	0.6	0.2	0.2	0.8	0.5	0.6	0.4	0.8	0.6	0.8	0.9	8.6
t:	1.952	0.410	-0.219	-0.762	-1.984	-2.397	-0.745	1.213	-1.618	0.332	-0.261	1.059	-0.824
Ho:	REJECT	NO REJ	NO REJ	NO REJ	REJECT	REJECT	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ	NO REJ
80-88:	DRIER				WETTER	WETTER							

Appendix H

Survey Report Forms

Cover Sheet for Regeneration Exams

USDA—FOREST SERVICE

REFORESTATION STOCKING SURVEY ANALYSIS FORM

Unit Name 310.7-22 Acres 43 approx 20 acres planted

Minimum Stocking Level ______ Trees per Acre see below Date 7/14/87

Plots/Acres ______ Plot Size 1/200

Surveyed by FD JM HM Title ______

Minimum Trees/Plot ______

Type of Survey	X		Sub-Compartment	X		Predominant Aspect	X	
State	XX		Sub-Unit	XX		Habitat Type	XXX	
County	XXX		Stand	XX		Timber Land Use	XXX	
Forest	XX		Acres	XXX		Project Description	X	
Block	X		Elevation	XX				
Compartment	XX		Slope Percent	X				

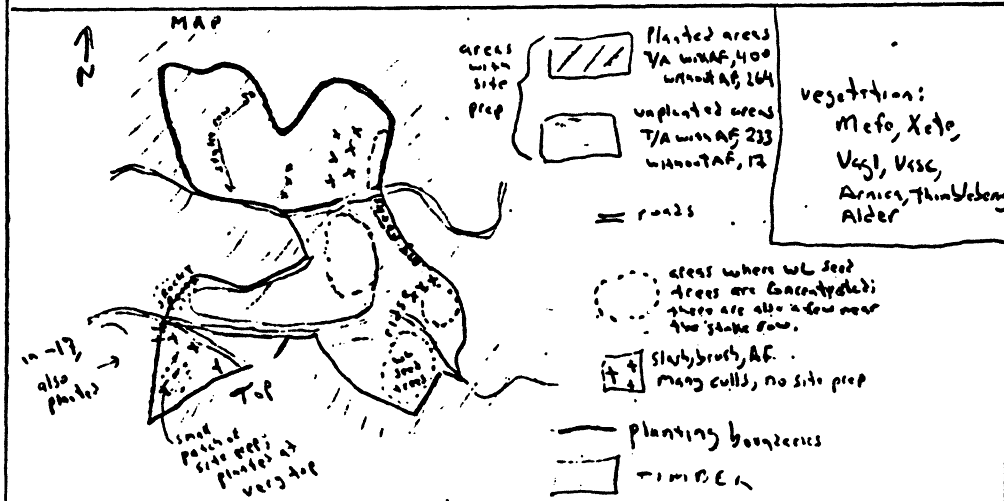
ANALYSIS

The majority of this unit has received adequate scarification and burning. The distribution of seed trees is not uniform, but planting has occured in various areas of the unit. Few WL have seeded in naturally so far, but it's really too soon for any substantial number to appear. Rocky areas are common.

Planted areas now have adequate stocking levels (see map.) Unplanted areas have, for the most part, decent amounts of bare soil and seed source. They are often rather rocky.

Rx: check in 2 years

Stake row results next page



R1-2470-18 (1/76)

Regeneration Exam Form

USDA FOREST SERVICE

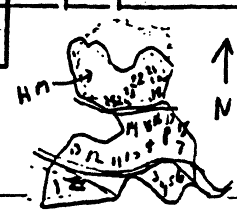
PAGE ___ OF ___

REFORESTATION STOCKING SURVEY FORM

UNIT NAME 3107-22 DATE 7/14/87 SURVEYED BY (43 acres) FD JM

1/100 acre plots

PLOT NUMBER	PLANTED (LP) SPECIES DF WL: HEALTHY	STRESSED	DEAD	NATURAL SPECIES: DF	ES	LP	WL		RESIDUAL: CULL	CROP	SEED TREE	TOTAL LIVE TREES IN PLOT not culls	PLOT STOCKING	PLOT CHARACTER CODE	REMARKS
1				2								2	0		Small planted LP close by
2	3LP								4AF 2"			3	3		
3				1 4"	1							2	1		good scarification
4												0	0		and burning
5				8AF 8-16"	1 2"				9AF			9	1		
6				1 4"								1	0		
7				1 1"								1	0		
8				2 1"								2	0		no site prep
9				1 2"								1	0		
10	1WL		1LP			1 2"						3	3		
11	1WL 2LP	1LP 1ES		2 7"								7	3		
1		1LP 1WL 1ES										3	3		
1	1LP	2LP										3	3		
14	ES			1								1	1		
15	LP											1	1		+1 ES <1' tall
16												0	0		
17				1 6"			1 3"		AF 1"			2	1		not planted
18												0	0		
TOTAL															



planting

Walk-Through Survey Example

USDA - FOREST SERVICE

5th Year Survey, LP & ES

REFORESTATION STOCKING SURVEY ANALYSIS FORM

Unit Name 310.7-29 Acres 3

Minimum Stocking Level ______ Trees per Acre ______ Date 9/15/87

Plots/Acres ______ Plot Size ______

Surveyed by FD Title ______

Minimum Trees/Plot ______

Type of Survey	X		Sub-Compartment	X		Predominant Aspect	X
State	XX		Sub-Unit	XX		Habitat Type	XXX
County	XXX		Stand	XX		Timber Land Use	XXX
Forest	XX		Acres	XXX		Project Description	X
Range	X		Elevation	XX			
Compartment	XX		Slope Percent	X			

ANALYSIS

Recent logging has removed ES & LP seed source, and left AF, from the north boundary. (See 311.2-27)

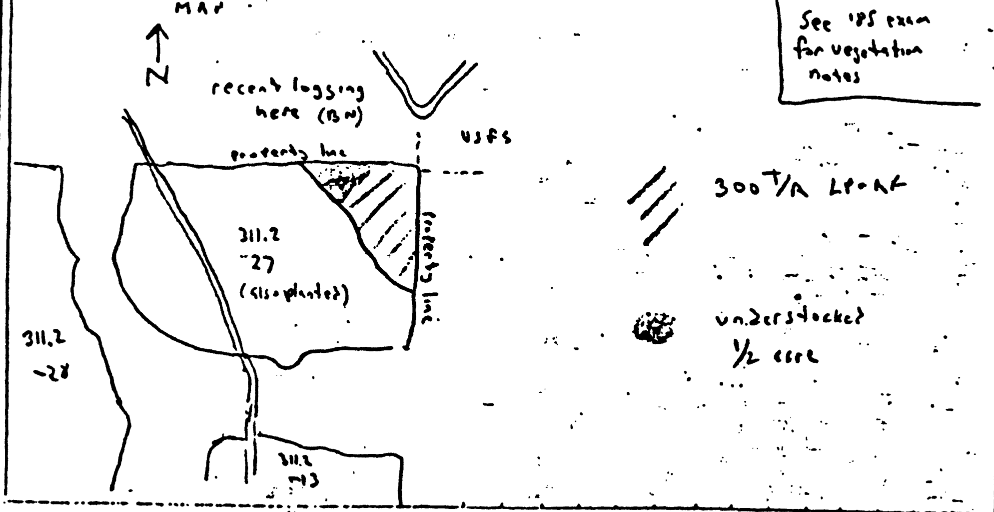
Otherwise, this unit is progressing. LP continue to seed in from the east timber wall, and planted LP are usually in good shape. ? Spruce don't always look so good.

Rx I recommended boosting stocking levels (on 311.2-27) near the north border. Could include the small corner of 29.

Whatever you decide for 311.2-27, write similar schedule for 310.7-29, i.e. plant excess LP or 4317 in 1990.

Brown felt blight on ES. Not serious.

MAP



R1-2470-18 (1/76)

Appendix I

Bootstrap Analysis for NATMOD and NAPLMOD

In this study, the data sets for the two regression models, NATMOD and NAPLMOD, included several surveys taken on the same stands at successive intervals. The assumption of temporal independence was probably violated because the stocking on a stand likely depends somewhat on the stocking of the same stand at a previous time. This results in autocorrelation which influences the variances of both the coefficients and the error term, resulting in less reliable predictions.

In order to test for autocorrelation in the models, a modified bootstrap[1] approach was used to examine the variance of coefficients obtained from similar data sets which were free of temporal dependence. The purpose of the bootstrap method is to create an accuracy interval around an estimate by generating numerous random samples from the original data set. The bootstrap accuracy interval is then determined from the estimates obtained from the replications, with the size of the interval positively related to the size of the variance of the bootstrap estimates.[2]

---

[1] The name "bootstrap" was coined to convey the self-help nature of the algorithm, which is closely related to the "jacknife" method introduced by Quenouille and Tukey (Efron, 1979).

[2] In Efron (1979), the accuracy interval is defined as the central 68% interval for the replicated coefficient values (the number of cases with less than the lower limit is 16% of the total number of cases and the number of cases with less than the upper limit is 84% of the total). The bootstrap estimate of the standard deviation is half the length of this interval. This non-parametric approach avoids the assumption of normality implied when the more common root mean square error is used as the standard deviation.

In the bootstrap method described by Efron (1979), replicated data sets are created by randomly selecting cases, with replacement, from an entire data set. In the modified bootstrap approach used in this study, all of the cases which were the only plot exams on a stand were selected at each replication, but for those stands with more than one exam over time, only one of the cases was selected (at random), resulting in 43 cases per data set (not all of the 54 study stands had plot exams). The BASIC program used for the randomization and selection process is reproduced at the end of this appendix.

The BASIC program was run 50 times, creating 50 replicated data sets for each of the two models.[3] A linear regression was performed on each data set, resulting in 50 sets of coefficients for each model.

Tables J-1 and J-2 show the means for the bootstrap coefficients (included for comparison), the bootstrap standard deviations, the model coefficients, and the bootstrap accuracy intervals.

Table J-1

Results from Bootstrap Replications of NATMOD

Variable	Bootstrap Mean	Bootstrap Std. Dev.	NATMOD Coeff.	Bootstrap Accuracy Interval
INTERCPT	-1805.7	285.65	1937.4	-2168.6 to -1597.3
ELEV	71.39	10.88	76.68	61.83 to 83.58
ELEV2	-.6869	.1122	-.7398	-.8095 to -.5851
BURN	-80.45	10.18	-66.23	-91.04 to -70.68
HABTYP	56.46	15.22	72.61	40.65 to 71.09
DIST_TO_EXAM2	3.174	.5005	2.730	2.712 to 3.713
THREE_VARS	.9390	.5700	1.174	.308 to 1.448
HARV_TO_DIST	15.94	2.660	14.65	13.36 to 18.68

[3]Efron (1979) recommended 250 to 1000 replications, which are more easily accommodated by large statistical packages.

Table J-2

Results from Bootstrap Replications of NAPLMOD

Variable	Bootstrap Mean	Bootstrap Std Dev.	NAPLMOD Coeff.	Bootstrap Accuracy Interval
INTERCPT	34.36	10.51	33.26	22.55 to 43.57
HABTYP	61.95	10.27	60.82	49.96 to 70.49
DIST_TO_EXAM2	4.033	0.424	3.820	3.644 to 4.472
THREE_VARS	.9173	0.497	1.060	.3529 to 1.346
PLANTD	240.5	25.68	241.8	210.2 to 263.6
PLANT_TO_EXAM	-47.09	13.02	-42.67	-60.45 to -34.42
DIST_TO_PLANT	-35.25	6.068	-36.77	-42.23 to -30.09

It is evident from Tables J-1 and J-2 that the means of the coefficients from the bootstrap samples are similar in sign and magnitude to the coefficients from the study models. In Table J-1, the model coefficients for BURN and HABTYP lie outside of the accuracy intervals, indicating that the effects of autocorrelation may have reduced their reliability in predicting the dependent variable of effective stocking of natural regeneration. The bootstrap standard deviation for THREE_VARS is relatively high; more replications would reduce the standard deviation and narrow the accuracy interval.

In Table J-2, the NAPLMOD coefficients correspond closely to the bootstrap means, and they all lie within the bootstrap accuracy intervals. The bootstrap standard deviation is relatively high for THREE_VARS, as it was for the NATMOD bootstrap sample; again, more replications would create a narrower accuracy interval.

I did not calculate an accuracy interval for the R-squared values, but in the bootstrap replications for NATMOD, the corrected R-squared values ranged from .394 to .614; in the NAPLMOD bootstrap replications, the R-squared values ranged from .399 to .619. Also, I made no changes in the final version of either model on the basis of the bootstrap results.

The following BASIC program was used to generate the 50 randomly selected samples:

```
REM                  REPLICATION FOR BOOTSTRAP
REM
DIM S(80,1), N(80,1), Y(80,1), X1(80,1), X2(80,1), X3(80,1), X4(80,1),
 X5(80,1), X6(80,1)
OPEN "C:\THES\QB\NPBOOT1.DAT" FOR INPUT AS 1
FOR I = 1 TO 80
REM
INPUT #1, S(I,1), N(I,1), Y(I,1), X1(I,1), X2(I,1), X3(I,1), X4(I,1),
 X5(I,1), X6(I,1)
NEXT I
CLOSE #1
REM
PRINT S(80,1), N(80,1)
INPUT "ENTER OUTPUT FILE NAME>>"; OUTFILE$
OPEN OUTFILE$ FOR INPUT AS #2
REM
RANDOMIZE
FOR I = 1 TO 80
      N = N(I,1)
            IF N = 1 THEN 200
      Z = RND
            PRINT Z
      FOR H = 1 TO N
            IF Z < H / N THEN 100
            IF I = 80 THEN 200
            I = I + 1
      NEXT H
100 PRINT #2, Y(I,1); X1(I,1); X2(I,1); X3(I,1); X4(I,1); X5(I,1);
 X6(I,1)
I= I + N - H
REM
GOTO 250
200 PRINT #2, Y(I,1); X1(I,1); X2(I,1); X3(I,1); X4(I,1); X5(I,1);
 X6(I,1)
REM
250 NEXT I
300 END
```

Appendix J

Notes of a Statistical Interest

Formulas for Two Probability Distributions

The formula for the binomial probability distribution is:

$$p(x) = \frac{n!}{x!(n-x)!} p^x q^{n-x}$$

where p = the probability of success on a single trial, q = 1 - p, n = the number of trials, and x = the number of successes in n trials.

The formula for the Poisson probability distribution is:

$$p(x) = \frac{\lambda^x e^{-\lambda}}{x!}$$

where λ = the mean number of events in a given unit of time or space, and e = 2.71828, the base of natural logarithms.

Random vs. Systematic Sampling

Random sampling, by its feature that any point within the area has an equal chance of being represented in the sample, allows one to compute an estimate of the precision of the mean, usually referred to as the standard error, which may then be used to test the significance of the estimate of the mean. Systematic sampling, on the other hand, may provide an estimate of the mean which is actually more accurate (closer to the true mean value for the population) than that given by random samples, but lacks an exact indication of its precision. The formula for the standard error from random sampling may be used to compute sampling error of a systematic survey; the result is an approximation which may be higher or lower than the actual precision, depending on the spatial pattern of the population of trees (Freese, 1962).

The most random sampling would be to take plots located at randomly selected coordinates, known as a "random walk." Since one objective of stocking surveys is to cover the entire stand in as short a time as possible, the random walk has seldom been used. Grieg-Smith (1957) made the following suggestion, known as restricted random sampling which would facilitate the representative coverage of systematic sampling while providing the necessary randomization of plot location: sudivide the area into blocks of similar size and locate the same number of plots at random within the blocks (Grieg-Smith, 1957).

BIBLIOGRAPHY

A list of published silvicultural studies related to regeneration in western Montana (not in Literature Cited):

Friedman, S. 1986. Natural regeneration-- genetic and seed aspects. USDA For. Serv. Report. Region 6. Portland, OR. 20 pp.

Lotan, J.E. and D.A. Perry. 1977. Fifth-year seed:seedling ratios of lodgepole pine by habitat type and seedbed preparation technique. U.S.D.A. Forest Service Research Note INT-239. Ogden, UT. 6 pp.

Lotan, J.E. and D.A. Perry. 1983. Ecology and Regeneration of Lodgepole Pine. U.S.D.A. Forest Service Agriculture Handbook No. 606. Washington, D.C.

Shearer, R.C., and W.C. Schmidt. 1969. Ponderosa pine cone and seed losses. J. For. 69: 370-372.

Shearer, R.C. 1977. Maturation of western larch cones and seeds. USDA For. Serv. Res. Paper INT-189. Intermtn. For. and Range Exper. Stn. Ogden, UT. 15 p.

Shearer, R.C. 1984. Influence of insects on Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco, and western larch, Larix occidentalis Nutt., cone and seed production. In: Proceedings of the Cone and Seed Insects Working Party Conference, IUFRO. Southeastern Forest Experiment Station, NC. Pp. 112-120.

Shearer, R.C. 1985a. Effects of elevation on Pseudotsuga menziesii var. glauca cone and seed maturity in western Montana. In: Proceedings of the International Symposium on Seed Problems Under Stressful Conditions. Ed. by J. Nather. Vienna, June 3-8, 1985. Pp. 79-90.

Shearer, R.C. 1985b. Proceedings-- Conifer Tree Seed in the Inland Mountain West Symposium. USDA For. Serv. Gen. Tech. Rep. INT-203. Ogden, UT. 289 pp.

Shearer, R.C. 1986. Insects and frost limit cone production of Larix occidentalis Nutt. In: Proceedings of the 2nd Conference of the Cone and Seed Insects Working Party of the International Union of Forestry Research Organisations. Sept. 3-5, 1986. Briancon, France. Pp. 205-215.

Shopmeyer, C.S. 1974. Seeds of Woody Plants of the United States. USDA For. Serv. Agric. Handbook 450. Washington, D.C. 883 pp.

Vogl, R.J. and C. Ryder. 1969. Effects of slash burning on conifer production in Montana's Mission Range. Northwest Sci. 43(3):135-147.

Literature Cited

Akhromeiko, A.I. 1965. Physiological basis for the establishment of hardy forests. Izdatel'stvo Lesnaya Promyshlennost, Moscow. Translated by Israel Program for Scientific Translation, 1968, Jerusalem. p. 6.

Allen, G.S. 1941. A basis for forecasting seed crops of some coniferous trees. J. For. 39:1014-1016.

Blake, G.M. 1976. Conifer establishment following broadcast burning in larch-fir forests. Research Summary Report. University of Montana, School of Forestry. Missoula, MT.

Boe, K N. 1954. Periodicity of cone crops for five Montana conifers. In: Proceedings, Mont. Acad. Sci. Vol. 14. Missoula, MT. Pp. 5-9.

Christopherson, A. and V. Applegate. 1987. Lolo National Forest regeneration risk assessment and stocking level guides. Manuscript available from Lolo National Forest, Missoula, MT. 89 pp.

Crossley, D. 1976. The ingress of regeneration following harvest and scarification of lodgepole pine stands. For. Chron. Vol. 52, No. 1. Pp. 12-17.

Daniel, T.W., J.A. Helms and F.S. Baker. 1979. Principles of Silviculture. McGraw-Hill Book Co. New York, NY.

DeByle, N. 1981. Clearcutting and fire in the larch/Douglas-fir forests of western Montana-a multifaceted research summary. U.S.D.A. Forest Service Gen. Tech. Report INT-99. Intrmtn. For. and Range Exper. Station, Ogden, UT. 73 pp.

Dolezal, S. 1982. Natural regeneration establishment models for northeastern Oregon and central Washington. M.S. Thesis, University of Idaho. Moscow, ID. 116 pp.

Edwards, D.G.W. 1985. Cone prediction, collecting and processing. In: Proceedings of a Symposium on Conifer Tree Seed in the Inland Mountain West. Comp. by R. Shearer. Missoula, MT. Pp. 78-102.

Efron, B. 1979. Computers and the theory of statistics: thinking the unthinkable. Society for Industrial and Applied Mathematics (SIAM) Review. 21(4): 460-80.

Eis, S. 1973. Cone production of Douglas-fir and grand fir and its climatic requirements. Can. J. For. Res. 3:61-70.

Fairweather, S.E. 1984 Sequential sampling for assessment of stocking adequacy. In: Symposium proceedings, Inventorying forest and other vegetation of the high latitude and high altitude regions. July 23-

26, 1984. Fairbanks, AL. Pp. 82-86.

Ferguson, D.E. and N.L. Crookston. 1984. User's guide to the regeneration establishment model- a prognosis model extension. USDA Forest Service Gen. Tech Report INT-161. Intermtn. For. and Range Exper. Station. Ogden, UT. 23 pp.

Ferguson, D.E., A.R. Stage and R.J. Boyd. 1986. Predicting regeneration in the grand fir-cedar-hemlock ecosystem of the northern Rocky Mountains. For. Sci. Monograph 26. 41 pp.

Fiedler, C.E. 1981. Analysis of regeneration in the subalpine fir zone of western Montana. Unpublished, available through author, School of Forestry, Univ. of Montana. Missoula, MT. 64 pp.

Fiedler, C.E. 1982. Regeneration of clearcuts within four habitat types in western Montana. In: Site preparation and fuels management on steep terrain. D.M. Baumgartner, ed. Pp. 139-147. Co-op Ext., Wash. State Univ., Pullman, WA. 179 pp.

Freese, F. 1962. Elementary Forest Sampling. Agriculture Handbook No. 232. U.S.D.A. Forest Service. 91 pp.

Grant, J.C. 1951. The relationship between stocking and size of quadrat. University of Toronto Forestry Bulletin. Toronto, Canada. 35 pp.

Greig-Smith, P. 1957. Quantitative Plant Ecology. Academic Press, Inc. New York. Pp. 50-66.

Hamilton, D.A., Jr. 1974. Event probabilities estimated by regression. U.S.D.A. For. Serv. Res. Pap. INT-152. Intermtn. For. and Range Exper. Stn. Ogden, UT. 18 pp.

Hamilton, D.A., Jr., and D.L.R. Wendt. 1975. SCREEN: a computer program to identify predictors of dichotomous dependent variables. USDA Forest Service Gen. Tech. Rep. INT-22. Intrmtn. For. and Range Exper. Stn. Ogden, UT. 20 pp.

Haynes, R.W. and D.M. Adams. 1980. The 1980 softwood timber assessment market model: structure, projections, and policy simulations. Forest Science Monograph 22.

Harry, L. 1986. Unpublished paper on defining stocking goals for lodgepole pine and predicting future stocking based on cone counts following logging. Available from the author. Beaverhead Natl. Forest, Dillon MT. 5 pp.

Kmenta, Jan. 1986. Elements of Econometrics. Macmillan Publishing Co. New York. Pp. 547-560.

Koutsoyiannis, A. 1983. Theory of Econometrics. The Macmillan Press Ltd. London. Pp. 200-217.

Lolo National Forest. 1985. Lolo National Forest integrated soil survey-- preliminary draft. Jan. 1985. Missoula, MT.

Lolo National Forest. 1986. The Lolo National Forest Plan. U.S.D.A Forest Serv. Lolo National Forest. Missoula, MT.

Lotan, J.E. and D.A. Perry. 1977. Fifth-year seed:seedling ratios of lodgepole pine by habitat type and seedbed preparation technique. U.S.D.A. For. Serv. Res. Note INT-239. Ogden, UT. 6 pp.

Lotan, J.E. and D.A. Perry. 1983. Ecology and Regeneration of Lodgepole Pine. U.S.D.A. Forest Service Agriculture Handbook No. 606. Washington, D.C.

Lowry, W.P. 1966. Apparent meteorological requirements for abundant cone crop in Douglas-fir. For. Sci. 12:185-192.

Lynch, D.W. and F.A. Schumacher. 1941. Concerning dispersion of natural regeneration. J.Forestry. 39(1): 49-51.

McClave, J.T. and F.H. Dietrich. 1982. Statistics. Dellen Publishing Co. San Francisco, CA.

McQuillan, A.G. 1981. Evaluating timberland allocation and managemnt intensity. Ph.d. Dissertation, University of Montana. Missoula, MT. P. 219.

McQuillan, A.G. 1987. Growth and yield for second-growth managed stands: some thoughts on measuring spatial distribution. In: Proceedings of Annual Meeting of Western For. and Cons. Asso. Dec. 1987. Seattle, WA.

McQuillan, A.G. 1989. Personal communication.

National Oceanic and Atmospheric Administration (NOAA). 1959-1988. Annual Summary of Climatological Data, Montana. U.S. Dept. of Commerce. Asheville, NC.

On, D. and B.J. Losensky. 1975. Ecoclass identification for Region 1. U.S.D.A. For. Serv. Unpublished report. Missoula, MT. 11 pp.

Persson, O. 1973. On forest regeneration surveys. Proc. of the Fourth Conf. of the Advisory Group of Forest Statisticians, IUFRO. Vancouver, B.C., Canada.

Pfister, R.D., B.L. Kovalchik, S.F. Arno, and R.C. Presby. 1977. Forest habitat types of Montana. USDA For. Serv. IFRES Gen. Tech. Rep. INT-34. Intermtn. For. and Range Exp. Sta. Ogden, UT. 174 pp.

Pielou, E.C. 1983. Ecological Diversity. John Wiley and Sons. New York. 165 pp.

Pielou, E.C. 1974. Population and Community Ecology. Gordon and Breach. New York. Pp. 133-165.

Pindyck, R.S. and D.L Rubinfeld. 1981. Econometric Models and Economic Forecasts. McGraw-Hill Book Co. New York. Pp. 273-315.

Roe, A.L. 1966. A procedure for forecasting western larch seed crops. USDA For. Serv. Res. Note INT-49. Intermtn. For. and Range Exper. Stn. Ogden, UT. 7 pp.

Running, S.W. 1982. A biophysical assessment of the regeneration and growth potential of forested land in Montana. In: Proceedings of a Symposium on Management of Second-Growth Forests-- The State of Knowledge and Research Needs. May 14, 1982. Missoula, MT. Pp. 58-75.

Ryker, R.A. 1975. A survey of factors affecting regeneration of Rocky Mountain Douglas-fir. U.S.D.A. For.Serv. Res. Paper INT-74. Intermtn. For and Range Exper. Stn. Ogden, UT. 14 pp.

Schmidt, W.C. and J.E. Lotan. 1980. Phenology of common forest flora of the northern Rockies. U.S.D.A. Forest Service Res. Paper INT-259. Intermtn. For. and Range Exper. Stn. Ogden, UT. 20 pp.

Shearer, R.C. 1984. Effects of prescribed burning and wildfire on regeneration in a larch forest in northwest Montana. In: New forests for a changing world: Proceedings of Soc. Amer. For. Natl. Conv. Oct. 1983. Portland, OR. pp. 266-270.

Shearer, R.C., compiler. 1985. Proceedings-- Conifer Tree Seed in the Inland Mountain West Symposium. Missoula, MT, Aug. 5-6, 1985. U.S.D.A. Forest Service Gen. Tech Rep. INT-203. Intermtn. For. and Range Exper. Stn. Ogden, UT. 289 pp.

Shearer, R.C. 1986. Western larch cones and seeds-- current Intermountain Research Station studies. In: Proceedings of Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting. Aug. 12-15, Tumwater, WA. USDA For. Serv. Gen. Tech. Rep. RM-137. Pp. 4-10.

Stage, A.R. 1973. Prognosis model for stand development. Res. Pap. INT-137. U.S.D.A. For. Serv. Intermtn. For. and Range Exper. Stn. Ogden, UT. 32 pp.

Stage, A.R. 1974. Picturing the future forest from regeneration surveys- a research program and scale for defining adequate stocking. In: Permanent Association Proceedings, 65th Western Forestry Conference, Dec. 3, 1974. Spokane, WA. pp. 74-76.

Stage, A.R. 1976. An expression for the effect of aspect, slope, and habitat type on tree growth. Forest Sci. 22:457-460.

Stage, A.R. 1987. Personal communication.

Stark, N. 1979. Nutrient losses from timber harvesting in a larch/Douglas-fir forest. U.S.D.A. Forest Service Res. Paper. INT-231. Intermtn. For. and Range Exper. Stn. Ogden, UT. 41 pp.

Stark, N. and D. Essig. 1985. Nutrient release from Mount St. Helens volcanic ash and retention by western Montana soil. USDA For. Serv. Intmtn. For. and Range Exper. Stn. Res. Paper INT-338. Ogden, UT.

Stein, W.I. 1983. Regeneration surveys: an overview. In: New forests For a Changing World: Proceedings of Soc. Amer. For. Natl. Conv. Oct. 1983. Portland, OR. pp. 11-115.

Stein, W.I. 1983. Fixed-plot methods for evaluating forest regeneration. Ibid. pp. 129-135.

U.S. Congress. 1974. Forest and Rangeland Renewable Resources Planning Act. 88 Stat. 476, as amended; 16 U.S.C. 1600-1614. Washington, D.C.

U.S. Congress. 1976. National Forest Management Act. 90 Stat. 2949; Public Law 94-588. Washington, D.C.

U.S.D.A. For. Serv. 1982. National Forest System Land and Resource Management Planning. 36 CFR Part 219. Washington, D.C.

U.S.D.A. For. Serv. 1973-1981. Forest Service Manual. Washington, D.C.

U.S.D.A. For. Serv. 1982-1988. Forest Service Handbook (FSH). Region 1, Missoula, MT.

U.S.D.A. For. Serv. 1985-1988. Reforestation Handbook, FSH 2409.26b. Region 1, Missoula, MT.

Van Vredenburch, C.L.H., and J.G.A. la Bastide. 1969. The influence of meteorological factors on the cone crop of Douglas-fir in the Netherlands. Silvae Genetica. 18:182-186.

Wellner, C.A. 1940. Relationships between three measures of stocking in natural reproduction of the western white pine type. J. For. 38: 636-638.